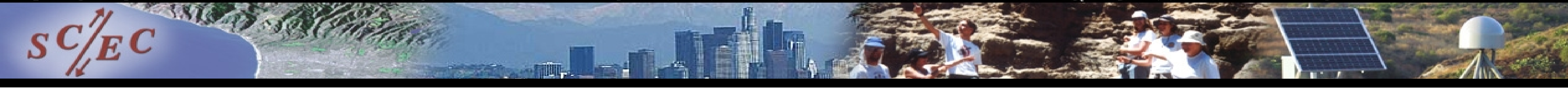



# Collaboratory for the Study of Earthquake Predictability

## (Probabilistic Estimates of Network Recording Completeness)

D. Schorlemmer (SCEC/USC)

Contributions from:
T. Jordan, M. Liukis, P. Maechling, J. Yu, J. Zechar (SCEC/USC)
J. Woessner, F. Euchner, S. Wiemer, C. Bachmann, E. Kissling, K. Nanjo (ETH)
F. Mele, W. Marzocchi, M. Cocco (INGV)
M. Gerstenberger (GNS)
D. Oppenheimer (USGS)

# Collaboratory for the Study of Earthquake Predictability (CSEP)

… is an open, international partnership to support a global program of research on earthquake predictability through prospective, comparative testing of scientific prediction hypotheses in a variety of tectonic environments.

# Three Definitions

- Earthquake predictability
  - degree to which the future occurrence of earthquakes is encoded in the behavior of an active fault system
- Scientific earthquake prediction
  - a testable hypothesis, usually stated in probabilistic terms, of the location, time, and size (and perhaps other parameters) of fault ruptures
- Useful earthquake prediction
  - advance warning of potentially destructive fault rupture precise and reliable enough to warrant actions to prepare communities

# Three Questions

Q1 How should scientific earthquake predictions be stated and tested?

- How should prediction experiments be conducted and evaluated?

Q2 What is the intrinsic predictability of the earthquake rupture process?

- What could we predict if we understood more about earthquake physics?

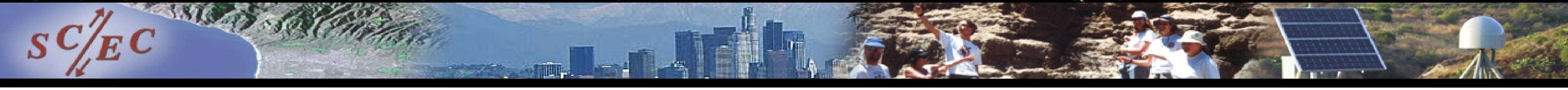
Q3 Can knowledge of large-earthquake predictability be deployed as useful predictions?

- Is operational earthquake prediction feasible?

# “Silver Bullet” Approach

- Seeks useful, short-term prediction of large earthquakes; i.e., focuses on direct answer to Q3
  - “heroic quest” for a simple solution
  - dominated research in the 1970’s and 1980’s
- Searches for signals diagnostic of approach to rupture, including:
  - foreshocks
  - strain-rate changes
  - electromagnetic signals
  - hydrologic changes
  - geochemical signals
  - animal behavior

- Has not thus far led to useful prediction methodologies




# Problems in Assessing Predictions

- Scientific publications provide insufficient information for independent evaluation
- Active researchers are constantly tweaking their procedures, which become moving targets
- Difficult to find resources to conduct and evaluate long-term prediction experiments
- Data to evaluate prediction experiments are often improperly specified
- Standards are lacking for testing predictions against reference forecasts

# CSEP Goals

1. Reduce the controversy surrounding earthquake prediction through a collaboratory infrastructure to support a wide range of scientific prediction experiments

2. Promote rigorous research on earthquake predictability through the SCEC program and its global partnerships

3. Help the responsible government agencies assess the feasibility of earthquake prediction and the performance of proposed prediction algorithms

# "Brick-by-Brick" Approach

- Focused on experimentation (Q1) and predictability (Q2), not operational and useful prediction (Q3)
  - Long-term effort to understand and improve predictability, even if probability gains are small
- Demonstrates predictability by rigorous testing based on *intercomparison* of models
  - RELM program and its extension to a Collaboratory for the Study of Earthquake Predictability (CSEP)

# CSEP Design

- Objective is to provide trustworthy answers to two questions
  - How was the earthquake prediction produced?
  - How was the earthquake prediction evaluated?
- Design goals
  - Data streams must be *authorized* and *calibrated*
  - Environment must be *controlled* and *transparent*
  - Results must be *reproducible* and *comparable*

# Four Essential CSEP Components

- **Testing centers**: facilities with validated procedures for conducting and evaluating prediction experiments
- **Community standards**: rules for the registration and evaluation of scientific prediction experiments
- **Communication protocols**: procedures for conveying scientific results and their significance
  - the scientific community, including professional societies
  - government agencies responsible for risk management
  - the general public and other end-users
- **Testing regions**: active fault systems with adequate, authorized data sources for conducting prediction experiments

# Testing Center

Hardware
2 Dual-Core AMD Opteron 2220
8 GB RAM
3.4 TB RAID 5 disks

OS/Kernel
Fedora Core 7 – 64 bit
2.6.22.1-41.fc7
gcc 4..1.2

Related Software
apache ant-1.7
R-2.5.0
elementtree-1.2.6-20050316
matplotlib-0.90.1
mpich2-1.0.3
CruiseControl

Identical hardware & software

www.cseptesting.org
Firewall
csep-op [operation]
csep-cert [certification]
Firewall
csep-devel [development]

**Webserver**
Restricted publication of results
Restricted dispatcher download
Test center setup information

**Operational Machine**
Automated Nightly builds from dispatcher
Publication of results to web server
Back up results
Quarterly Implementation of new models

**Integration/Cert Machine**
Automated Nightly builds from dispatcher
Emulates actual operation machine
Fulfill software dependencies
Implementation of new models

**Development Machine**
Import new models
Develop dispatcher
Fulfill software dependencies


# Web Collaboration System

trac
Integrated SCM & Project Management

Search
logged in as liukis | Logout | Settings | Help/Guide | About Trac

Wiki | Timeline | Roadmap | Browse Source | View Tickets | New Ticket | Search

Available Reports | Custom Query

## {6} All Tickets By Milestone (Including closed) (70 matches)

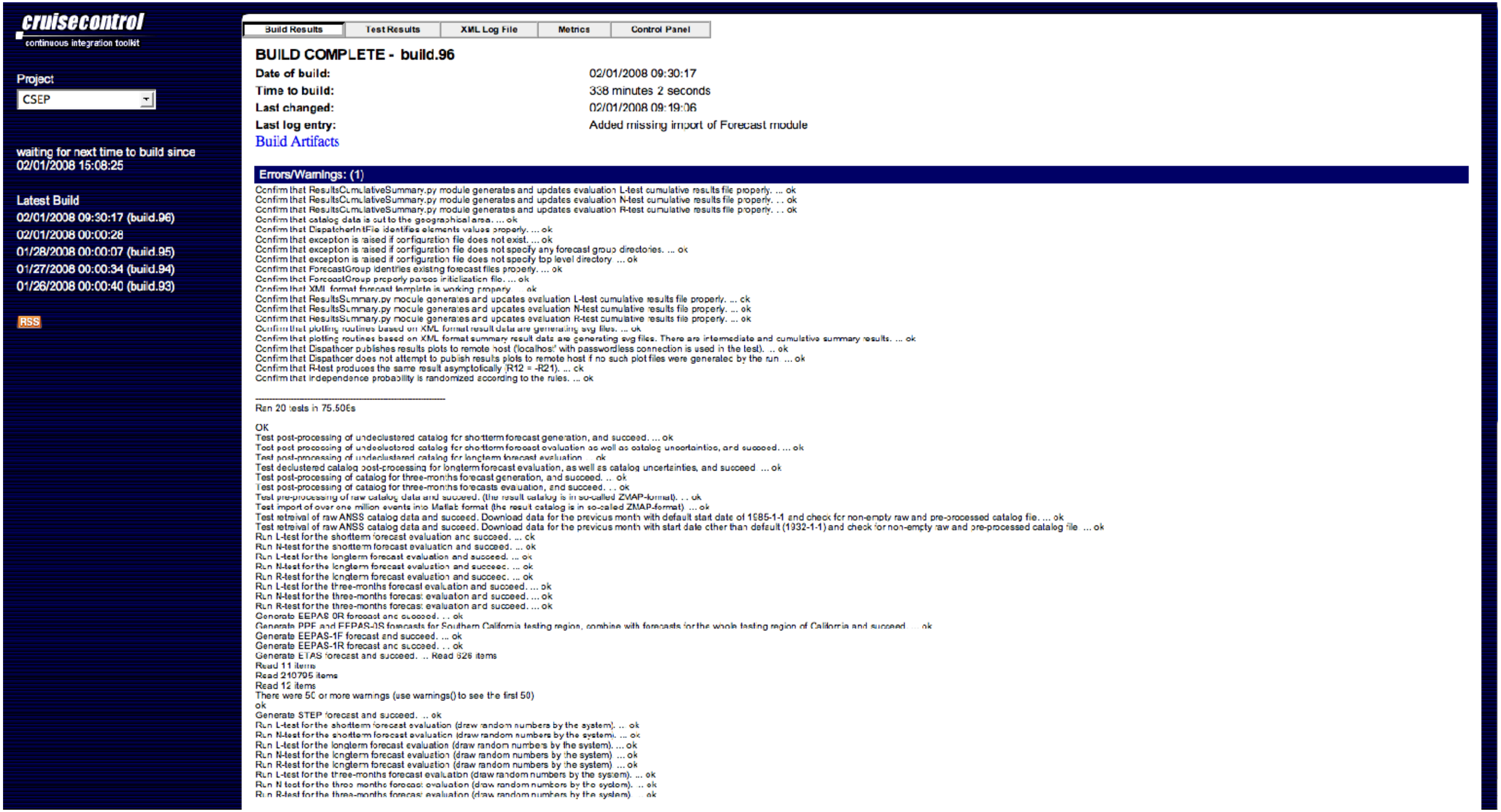
A more complex example to show how to make advanced reports.

Edit report | Copy report | Delete report

### Basic Test Center - Version 8.4

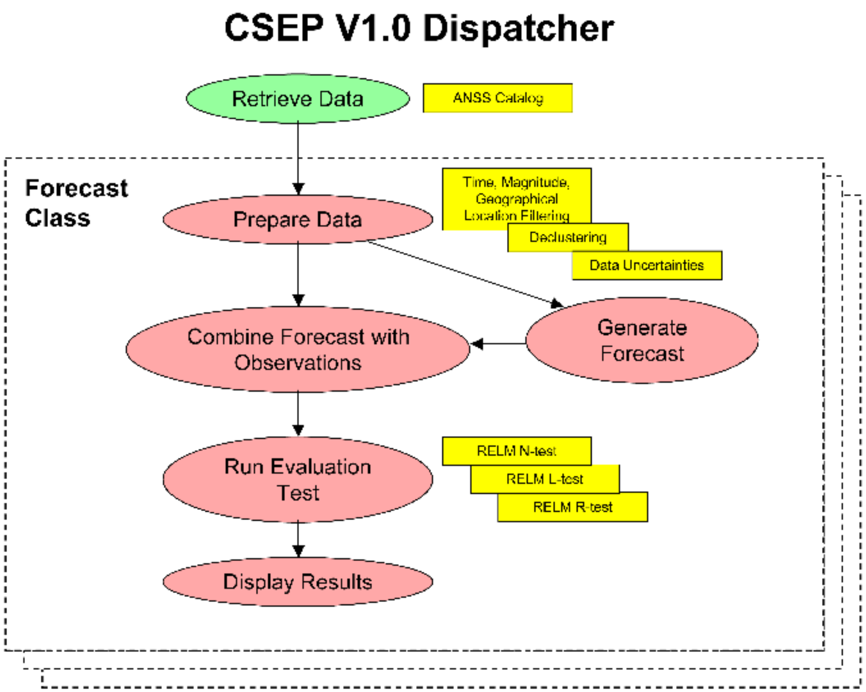
| Ticket | Summary | Component | Status | Resolution | Version | Type | Priority | Owner | Modified |
|---|---|---|---|---|---|---|---|---|---|
| #3 | Install Yan's one-day model on motion.usc.edu | NaturalLaboratory | new | None | 1.0 | task | major | somebody | 05/29/07 |
| #4 | Set up Yan' model one-day test scenario | NaturalLaboratory | new | None | 1.0 | task | major | somebody | 05/29/07 |
| #14 | Distribution of codes | Toolkit | assigned | None | 1.0 | task | major | liukis | 01/08/08 |
| #15 | Example data formats | DataTypes | new | None | 1.0 | task | major | somebody | 05/10/07 |
| #16 | Code documentation | Documentation | new | None | 2.0 | task | major | somebody | 09/04/07 |
| #21 | CSEP Testing Center Policy report | Documentation | new | None | 2.0 | task | major | somebody | 09/19/07 |
| #22 | Create form letter response | Documentation | new | None | 1.0 | task | major | somebody | 05/29/07 |
| #26 | Results reproducibility exercise. | Toolkit | assigned | None | 1.0 | task | major | liukis | 08/30/07 |
| #36 | Re-implement RELM evaluation N-test in Python without the use of random numbers | Toolkit | assigned | None | 2.0 | task | major | liukis | 01/24/08 |
| #38 | Generate CSEP Testing Center Technical report | Documentation | new | None | 2.0 | task | major | somebody | 09/19/07 |
| #40 | Archive yum updates and develop policy for updating csep_operational | Documentation | new | None | 2.0 | task | major | somebody | 09/19/07 |
| #42 | Setup matlab stand alone license manager | Toolkit | new | None | 2.0 | task | major | somebody | 09/19/07 |
| #44 | Describe techniques for checking evaluation algorithms | Documentation | new | None | 2.0 | task | major | somebody | 09/19/07 |
| #45 | Setup monitoring system (such as big brother) for csep_operational | NaturalLaboratory | new | None | 2.0 | task | major | somebody | 09/19/07 |
| #47 | Install Max Werner's one-day ETAS model | NaturalLaboratory | new | None | 2.0 | task | major | somebody | 09/19/07 |
| #49 | Look at possibility of making dispatcher runs completely independent. | Toolkit | assigned | None | 2.0 | enhancement | major | liukis | 10/29/07 |
| #50 | Display image of the forecast or result web-page | Toolkit | new | None | 2.0 | enhancement | major | somebody | 09/24/07 |
| #51 | Consider rewriting/invoking Fortran declustering code in Python | Toolkit | new | None | 2.0 | task | major | somebody | 09/24/07 |
| #52 | Construct csep_operational disk transfer verification and disk cleanup | Hardware | new | None | 2.0 | task | major | somebody | 09/25/07 |
| #58 | Add unit test to exercise pre-processing of ANSS catalog data and passing that data to forecast model | NaturalLaboratory | new | None | 2.0 | task | major | somebody | 11/08/07 |
| #59 | Add encryption to the email account password used by Dispatcher | DataTypes | new | None | 2.0 | enhancement | major | somebody | 11/29/07 |
| #60 | Investigate increasing of the Matlab recursive limit for STEP one-day model | NaturalLaboratory | new | None | 2.0 | defect | major | somebody | 11/30/07 |
| #63 | Test dates that were processed with V1.0 should be reprocessed with V8.1 | NaturalLaboratory | assigned | None | | task | major | liukis | 01/14/08 |
| #64 | Add CMT authorized data source | Toolkit | assigned | None | | task | major | liukis | 01/15/08 |
| #66 | Re-implement RELM evaluation L-test in Python without the use of random numbers | Toolkit | new | None | | enhancement | major | somebody | 01/24/08 |
| #67 | Re-implement RELM evaluation R-test in Python without the use of random numbers | Toolkit | new | None | | enhancement | major | somebody | 01/24/08 |
| #68 | Adopt QuakeML format for catalog data | Toolkit | new | None | | task | major | somebody | 01/24/08 |
| #43 | Setup automated retries for ANSS catalog data access | Toolkit | new | None | 2.0 | enhancement | minor | somebody | 09/25/07 |
| #65 | Create metadata file for each newly generated forecast file | Toolkit | closed | fixed | | task | major | liukis | 02/01/08 |
| #41 | Setup a copy of all daily results needed for reproducibility to USC HPCC account | Hardware | closed | fixed | 2.0 | task | major | somebody | 02/01/08 |
| #69 | Don't invoke archive and ssh commands for result publishing if no evaluation tests have been invoked | Toolkit | closed | fixed | | defect | major | liukis | 01/29/08 |
| #55 | Post warning notice about ANSS events used by SCEC testing center V1.0 | NaturalLaboratory | closed | invalid | 2.0 | task | major | somebody | 01/17/08 |
| #62 | File IO approach used by Python random number generator doubles up the processing time | Toolkit | closed | fixed | | defect | major | liukis | 01/17/08 |
| #61 | getCatalog_Import.m cannot import over 1 million of catalog events | Toolkit | closed | fixed | | defect | major | liukis | 01/15/08 |


# Automated Build System



# CSEP Testing Center Software

- Daily Automated Earthquake Forecast Generation
  - STEP, ETAS forecast models
- Automated Earthquake Forecast Evaluation
  - RELM *N*, *L* and *R* tests
- Automated Testing Framework
  - Acceptance tests
- Reproducibility of Results
  - Software version control
  - System configuration archive
  - Data set archive
- Identical Integration and Operational Systems
  - Common, standardized open-source software stack



# Milestones

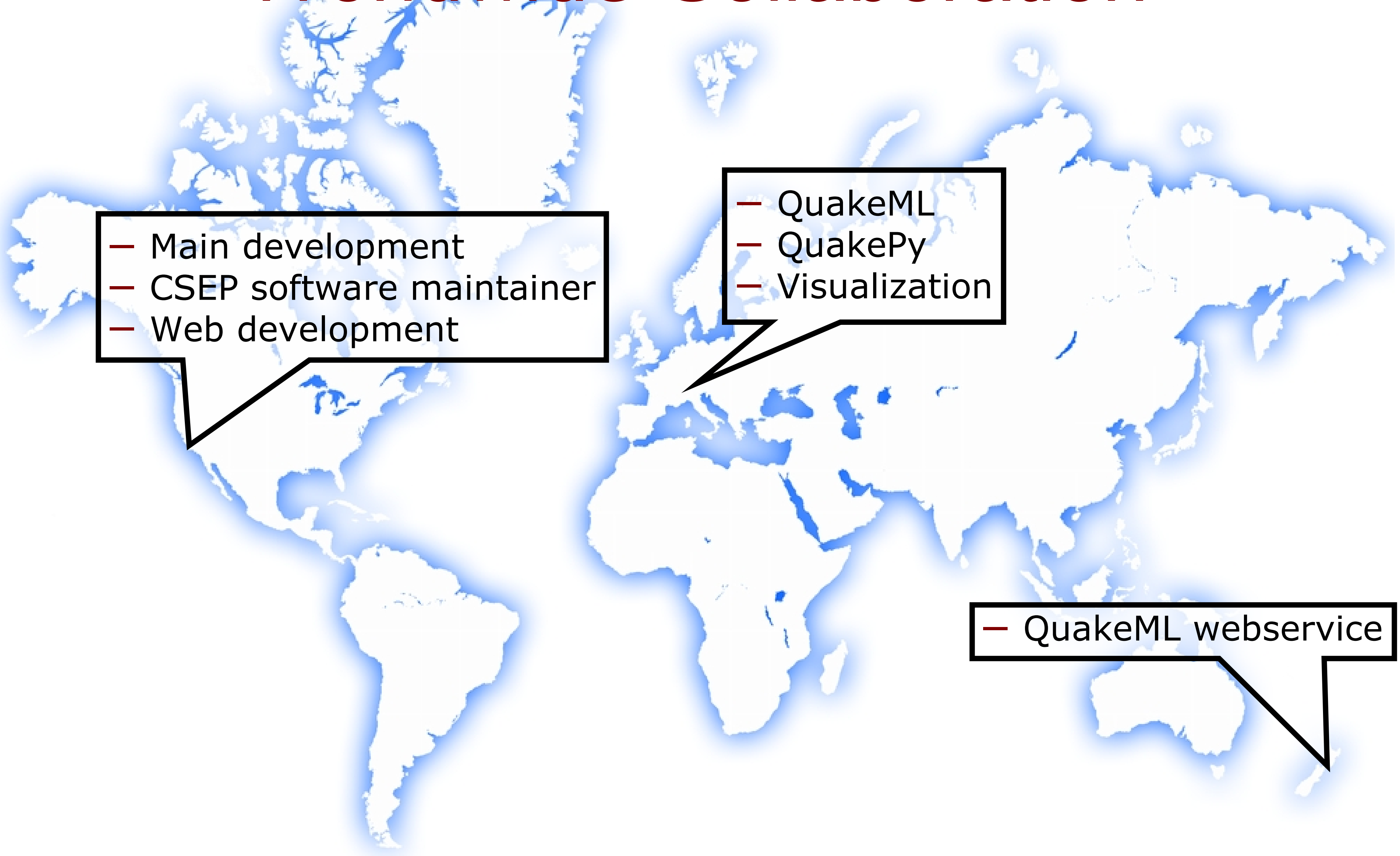
1 September 2007
- Release of CSEP Testing Center Software 1.0
- Operational system up and running
- 19 RELM 5-year models under test

1 January 2008
- Release of CSEP Testing Center Software 8.1
- First 1-day and 3-month models under test
- New Zealand operational and manually testing
- Europe operational

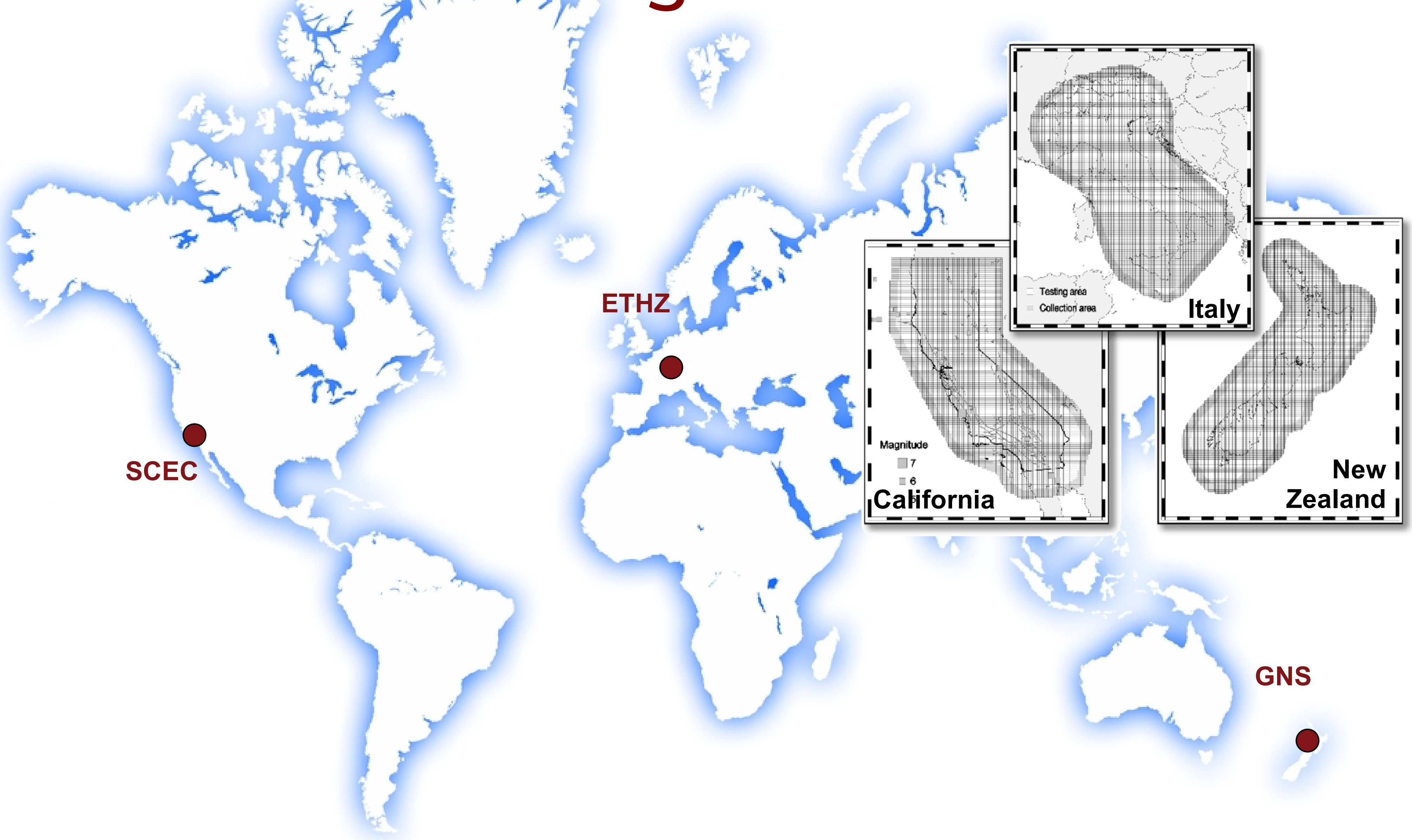
1 April 2008
- Release CSEP Testing Center Software 8.4
- Optimizations

1 July 2008
- Release CSEP Testing Center Software 8.7
- Western Pacific testing

# Worldwide Collaboration

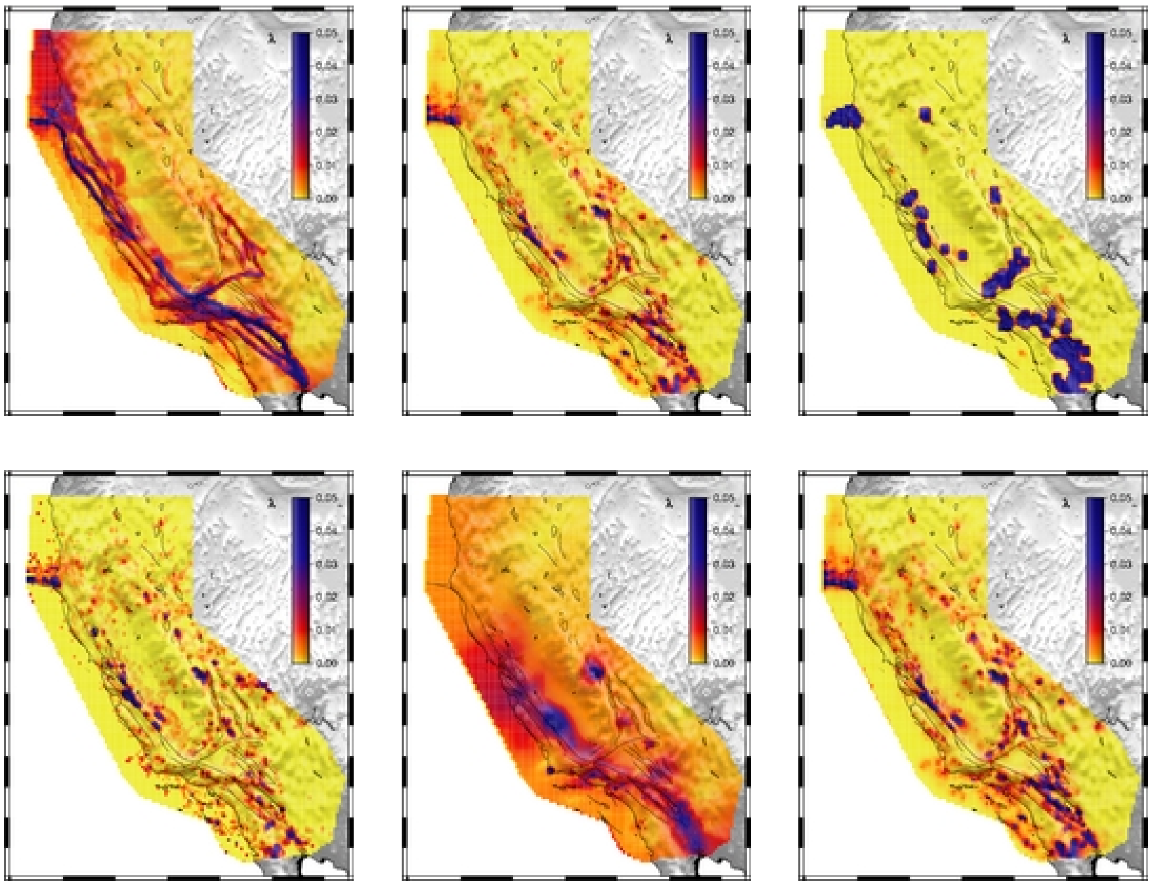


# Testing Center



# Testing Center (California)

19 5-year models have been submitted to the Testing Center



**Bird & Liu**
SHIFT main shock model
SHIFT main shock + aftershock model

**Ebel et al.**
5-yr main shock+aftershock model
5-yr main shock model

**Helmstetter, Kagan, Jackson**
HKJ 2005 long-term main shock model
HKJ 2005 long-term main shock + aftershock model

**Holliday et al.**
Pattern Informatics

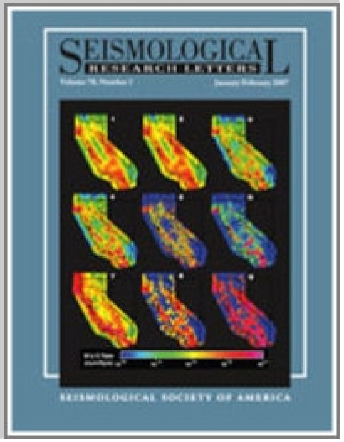
**Kagan et al.**
5-yr main shock model
5-yr main shock + aftershock model

**Shen, Jackson, and Kagan**
Geodetic main shock model
Geodetic main shock + aftershock model

**Ward**
combo81
geodetic81
geodetic85
geologic81
seismic81
simulation

**WG 2002**
National Hazard Model

**Wiemer & Schorlemmer**
Asperity Likelihood Model



# Community Standards

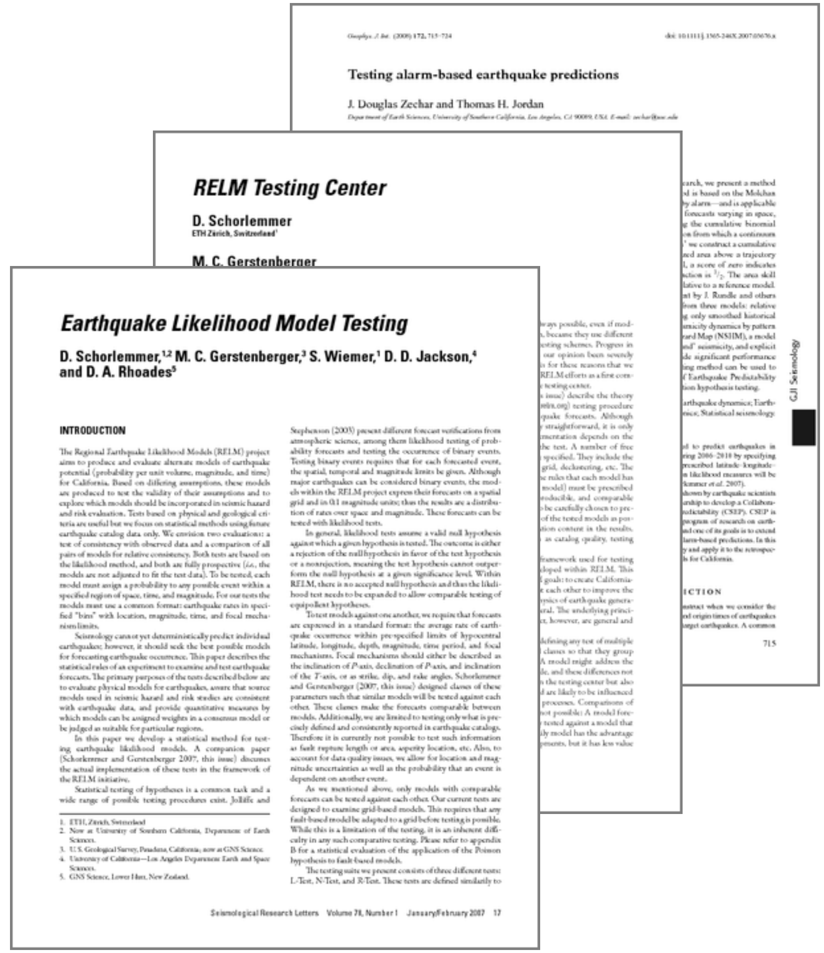
## Working Groups

### Data
- Working together with ANSS
- Review Process of work in Italy

### Global & Model
- Meeting 21 April 2008

### Cyberinfrastructure
- Software review meeting on 19 November 2007 at USC

### Testing
- Meeting 5 February 2008


Testing alarm-based earthquake predictions

J. Douglas Zechar and Thomas H. Jordan

RELM Testing Center

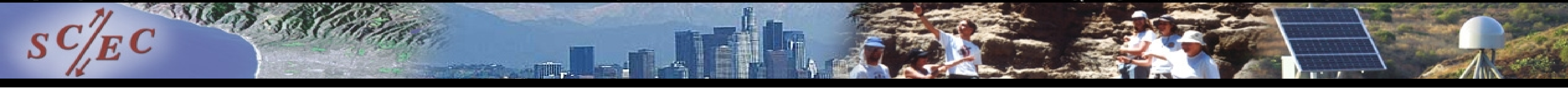
D. Schorlemmer

M. C. Gerstenberger

Earthquake Likelihood Model Testing

D. Schorlemmer, M. C. Gerstenberger, S. Wiemer, D. D. Jackson, and D. A. Rhoades

INTRODUCTION




# Grid-based Testing

- Standard testing schema as developed for RELM

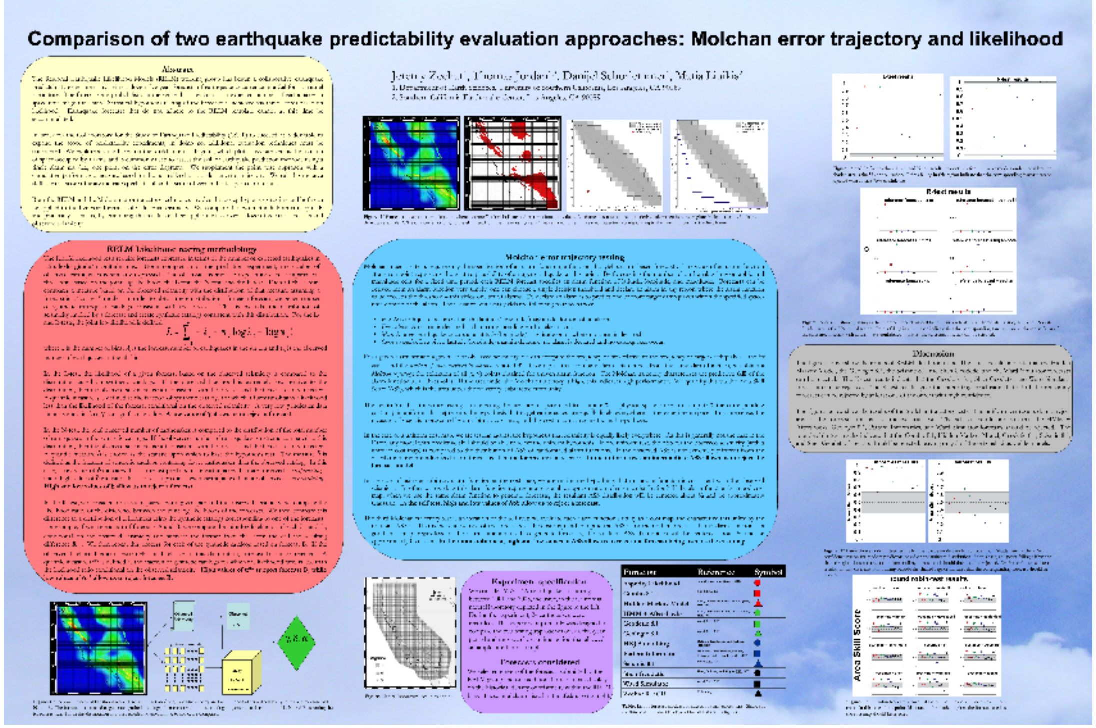
- Reduced large storage demands of current likelihood tests (RELM Tests)

- Rhoades & Schorlemmer are working on optimized version of likelihood tests
  - Reduce number of computation steps
  - Partly implemented in version 8.4

- Jackson, Kagan, & Schorlemmer are working on modified likelihood tests
  - Include different probability distributions
  - Allows for including uncertainties in forecast generation

# Alarm-based Testing

- Different methods exist (Molchan, ROC, etc.)
- Zechar is working to introduce the ASS (Area Skill Score) to version 8.10
- Comparison of results with likelihood testing



# Fault-based Testing

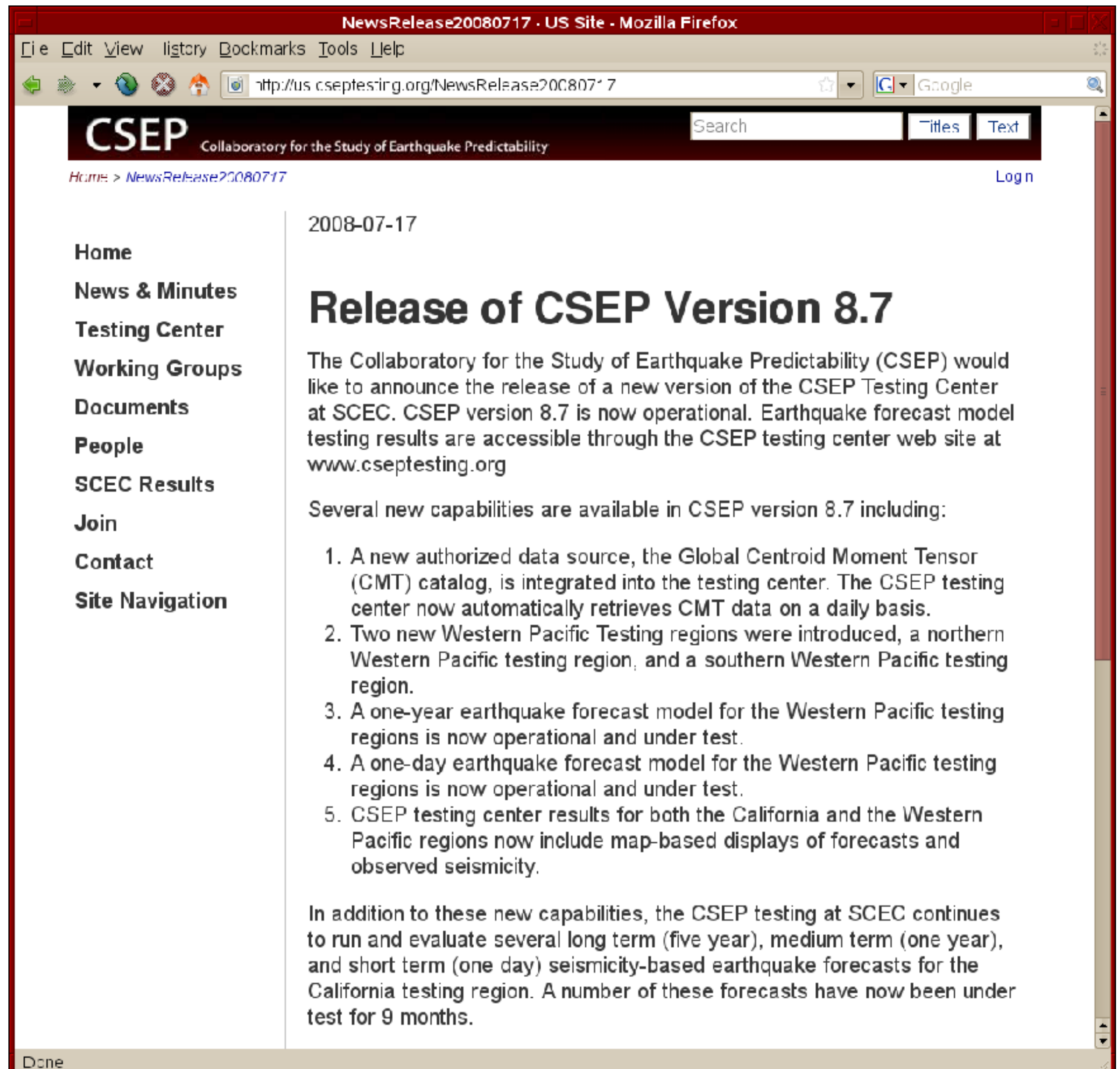
- Meeting held in April 2007 at USC
- No appropriate authorized data source identified
  - How to determine the ruptured fault?
  - How to determine the affected fault segments?
  - What about earthquake off known faults?
- Grid-based testing with focal mechanism information
  - SCEC community fault model
- Jackson, Kagan, and Schorlemmer are assessing possible earthquake data sources
- No implementation plans yet


# Communication Protocols

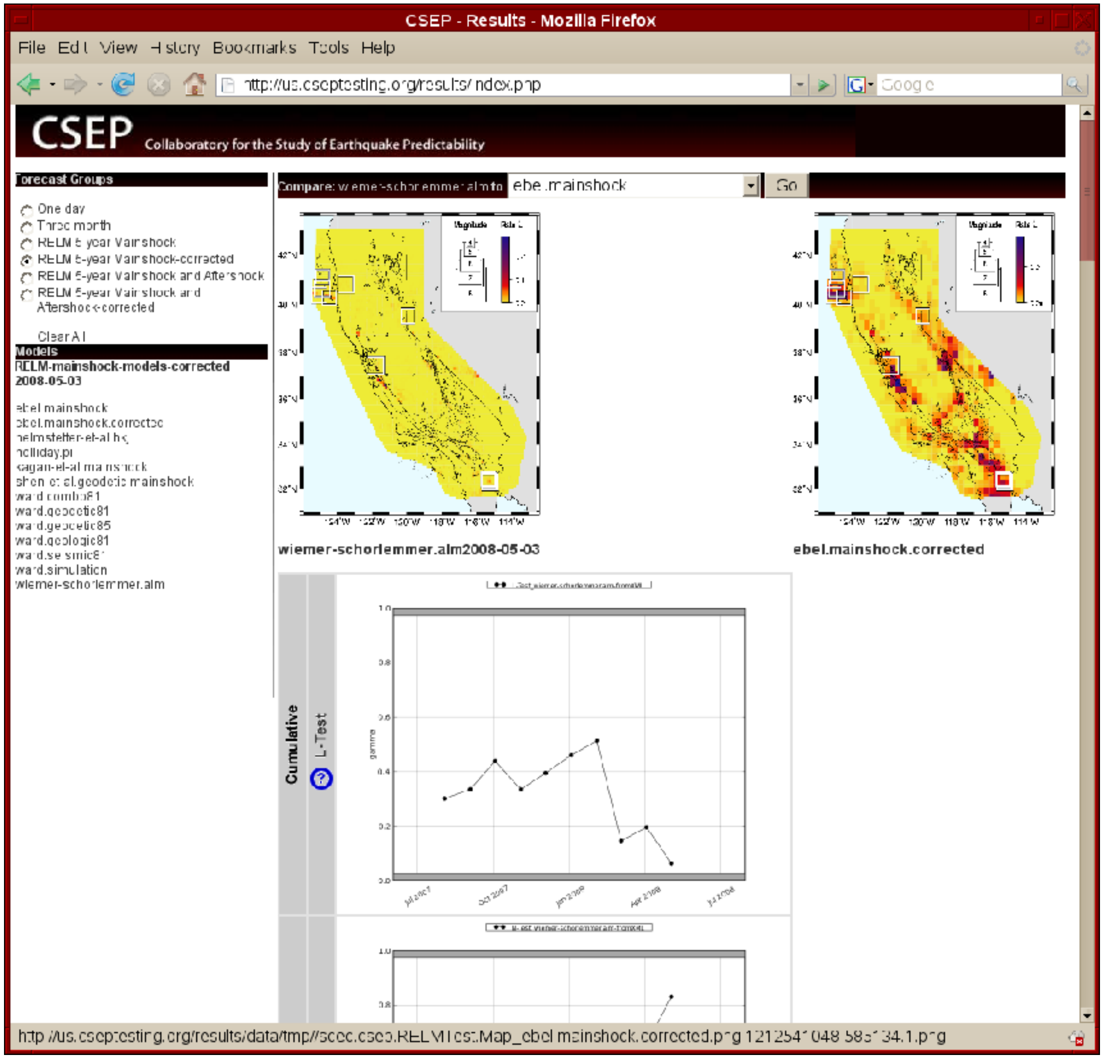
– News Releases

– Mailing lists

– Weekly minutes posted on website



# Communication Protocols




– Result webpages

– CSEP reports to CEPEC & NEPEC

# CSEP Web-Presentation Concept

**3 Websites**

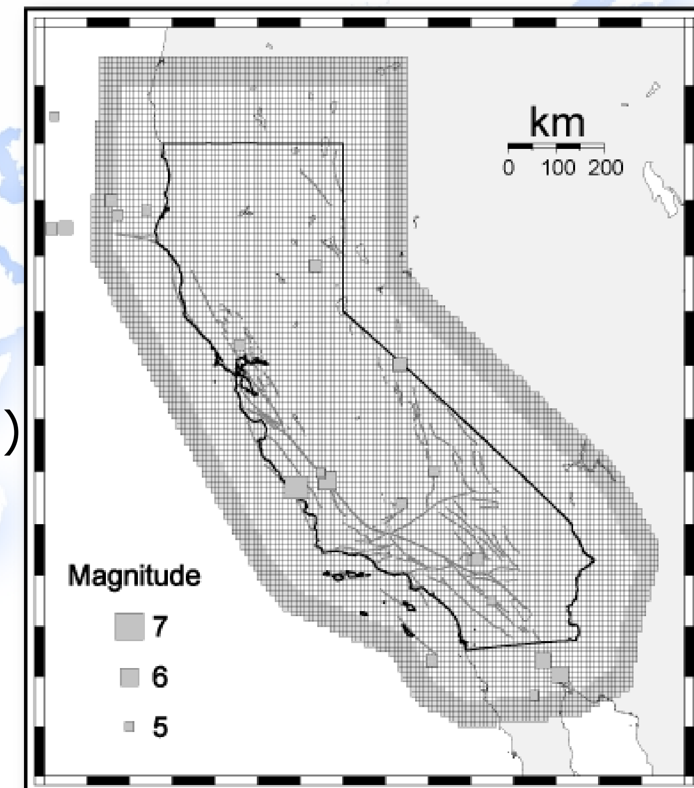
- Main CSEP website www.cseptesting.org (static)
- Regional websites (editable)
  - us.cseptesting.org
  - nz.cseptesting.org
  - eu.cseptesting.org
  - jp.cseptesting.org
- Result pages us.cseptesting.org/ScecResults (restricted)
  - Other centers can use this facility for their results

# Testing Regions

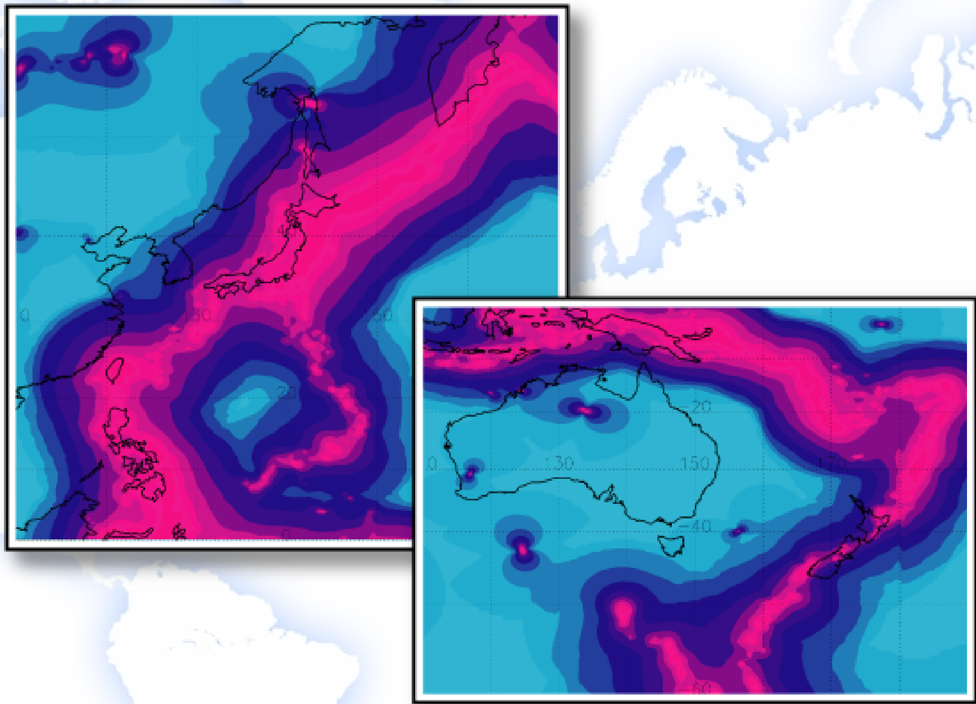
- Delineated region with defined areas for data collection and prediction testing
- Sponsorship by a regional organization of earthquake scientists willing to participate in CSEP
- Data streams authorized by agreements with appropriate regional agencies, including a low-latency earthquake catalog for testing prospective predictions
- Calibration of the seismic networks, including the quantification of hypocenter & magnitude uncertainties and mapping of completeness thresholds

# California

- Operational since 1.9.2007
- Current models
  - 5-year RELM
  - 1-day STEP & ETAS
  - 3-month EEPAS & PPE
- Upcoming models
  - ETAS (Werner)
  - Cellular Seismology (Kafka)
  - STEP Java (Gerstenberger)



# Western Pacific



- Covers >50% of worldwide seismicy
- Testbed for global testing
- Testbed for Global CMT catalog
- Implementation in 2008 (8.7)

# Basin & Range

- Meeting held in April at USC
- Area covered by 7 networks
- ANSS does not provide sufficient data quality
- No models available
- Not likely to happen

# New Zealand

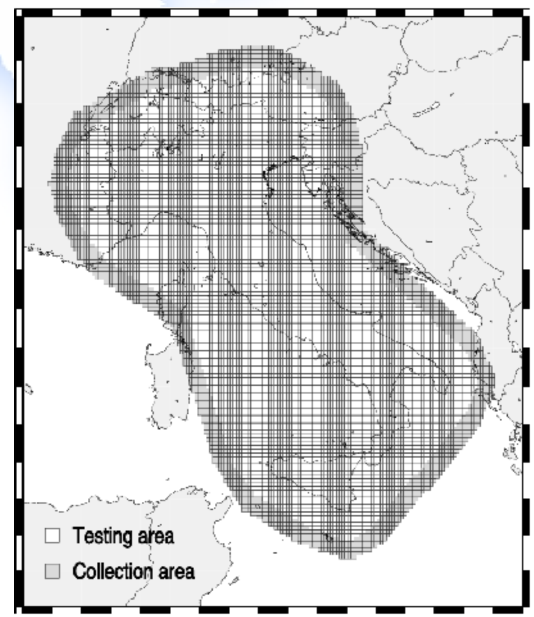
- Testing area defined
- Catalog including location parameter uncertainties
- Assumed overall completeness at M=4
- Declustering (same method as used in national hazard assessment)

- RELM Tests (N-, L-, and R-Test)
- New tests under development

- Models
  - 4 5-year models
  - 4 3-month models
  - 4 1-day models

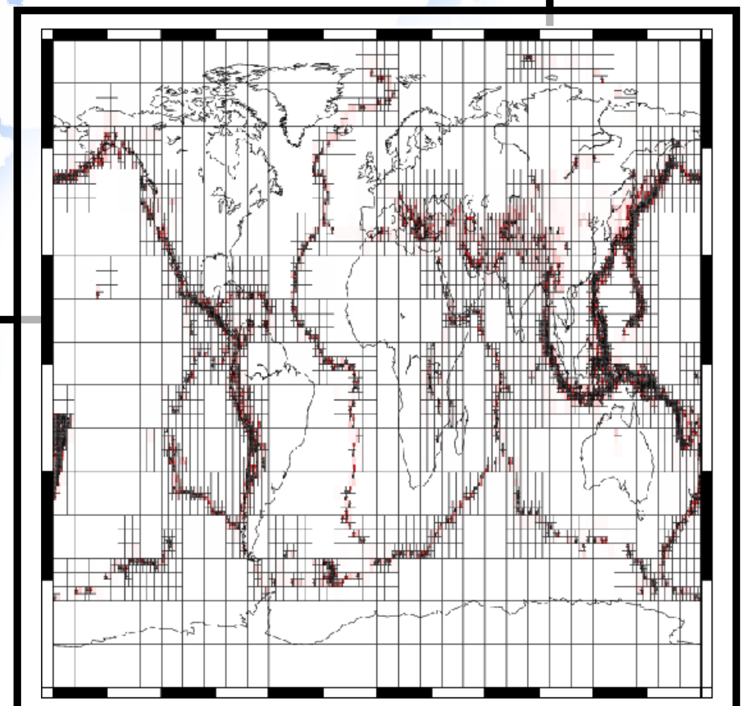
# Europe

- ETH Testing Center operational
- Implementation of testing region Italy underway
- Next possible regions (to be tested at ETH)
  - Greece
  - Iceland
  - Turkey
- Use the SCEC facilities for web presentations

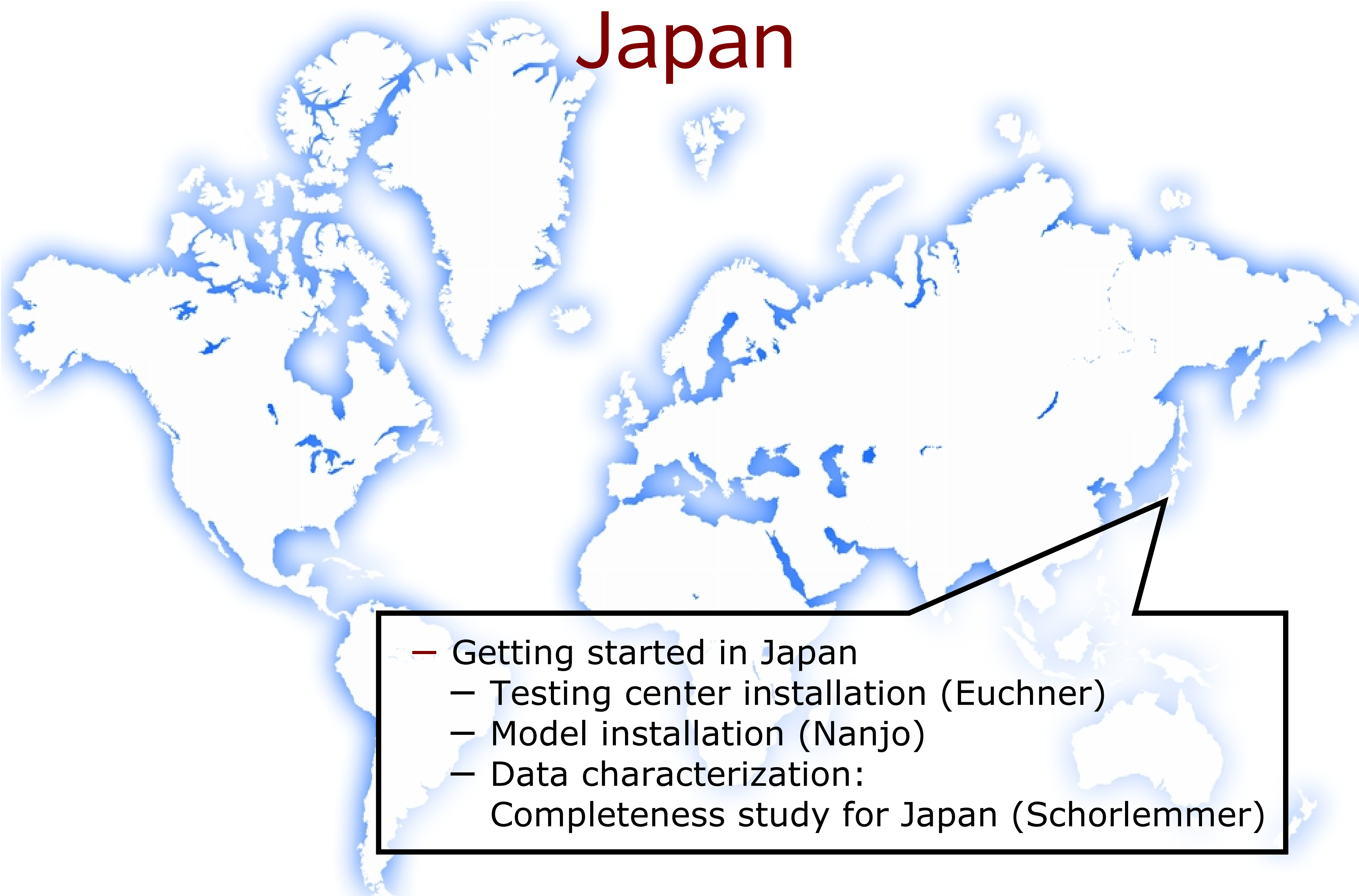


# Global

- First steps taken
- 3 testing area definitions
  - uniform grid
  - uniform grid covering only seismically active areas
  - non-uniform grid (importance grid)
- Models
  - Expand Western Pacific models for global testing
  - EEPAS/PPE models
  - Smoothed seismicity
  - GALM
- Global CMT catalog
- Global completeness study



# Japan



- Getting started in Japan
  - Testing center installation (Euchner)
  - Model installation (Nanjo)
  - Data characterization:
    Completeness study for Japan (Schorlemmer)

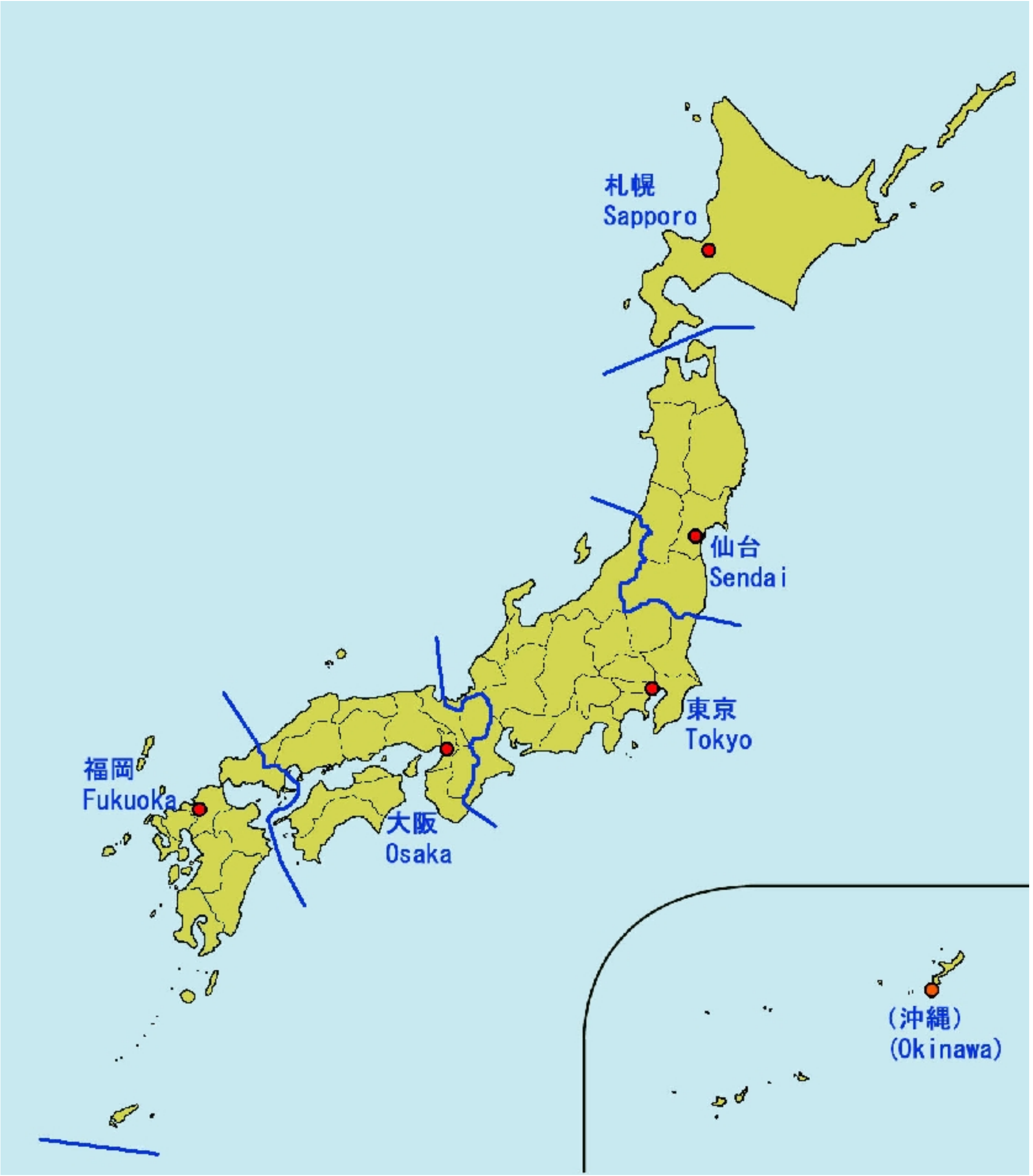
# Japan

JMA (+HiNet)

- ~1000 stations
- 6 districts
- overall high data quality

Important for CSEP:

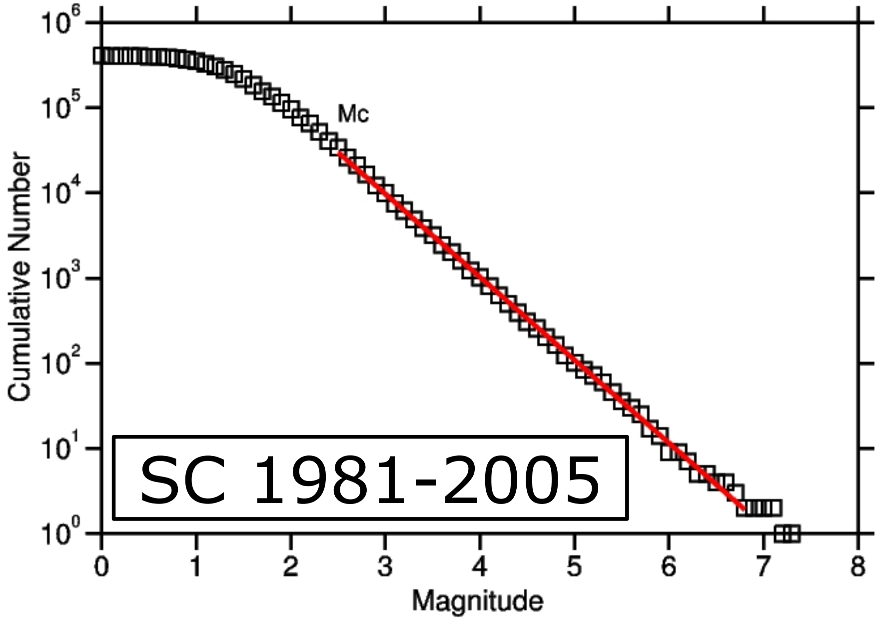
- completeness of deep seismicity
- offshore completeness
- homogeneity of reporting



# What is Completeness?

Completeness is usually defined as the magnitude of completeness, $M_c$:

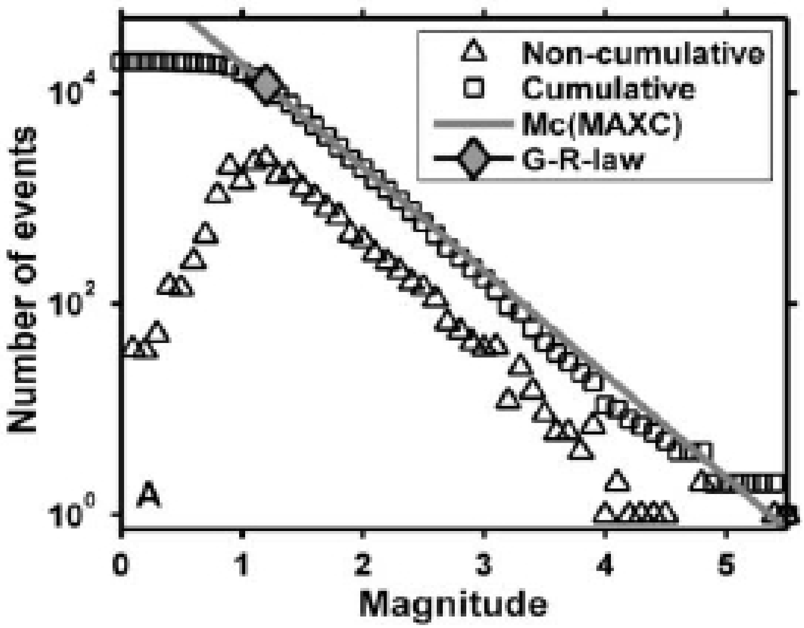
- $M_c$ describes the magnitude of the smallest events completely detected by the network.
- $M_c$ itself is defined as the deviation point from the "Gutenberg-Richter"-line in a frequency-magnitude distribution of an earthquake sample.



# Traditional Methods

Maximum Curvature

- Defines $M_c$ as the magnitude value with the highest curvature in the frequency-magnitude distribution.
- The non-cumulative magnitude bin with the highest number of events
- SCSN catalog with 0.01 binning needs to be rebinned to 0.1

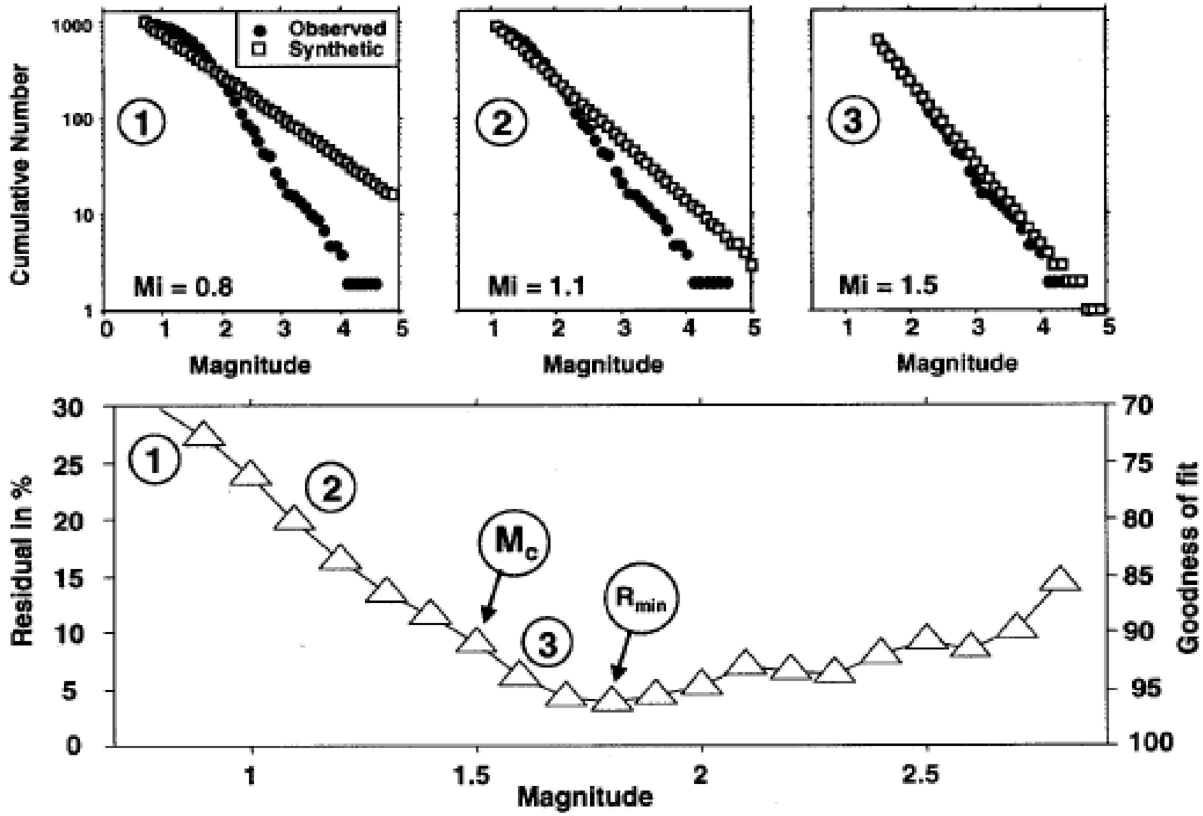



Woessner & Wiemer [2005]

# Traditional Methods

<u>Goodness of Fit</u>

– Searches through the magnitude space and measures the goodness of fit of the b-value line.
– Does often not reach the desired 90% level.

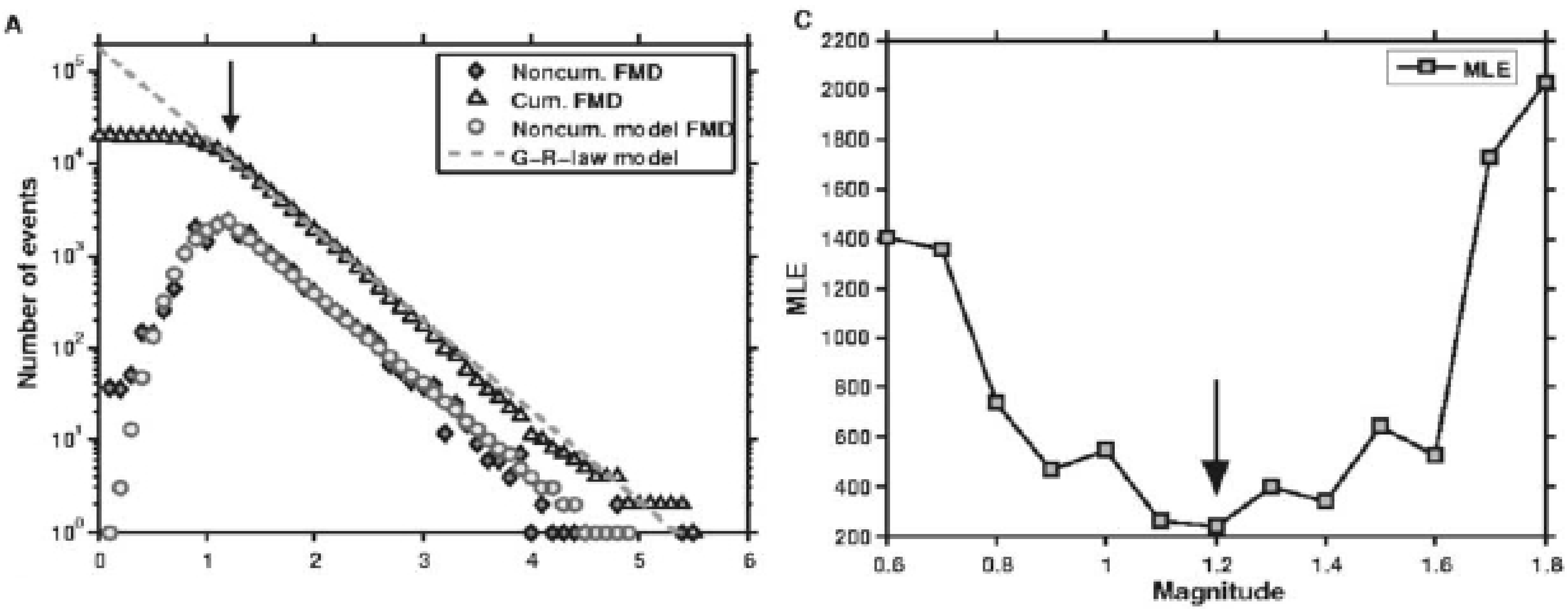



Wiemer & Wyss [2000]

# Traditional Methods

Entire Magnitude Range (EMR)

– Searches also through the magnitude space but assumes power-law and log-normal distributions.
– Method with the largest number of assumptions.




Woessner & Wiemer [2005]

# Traditional Methods

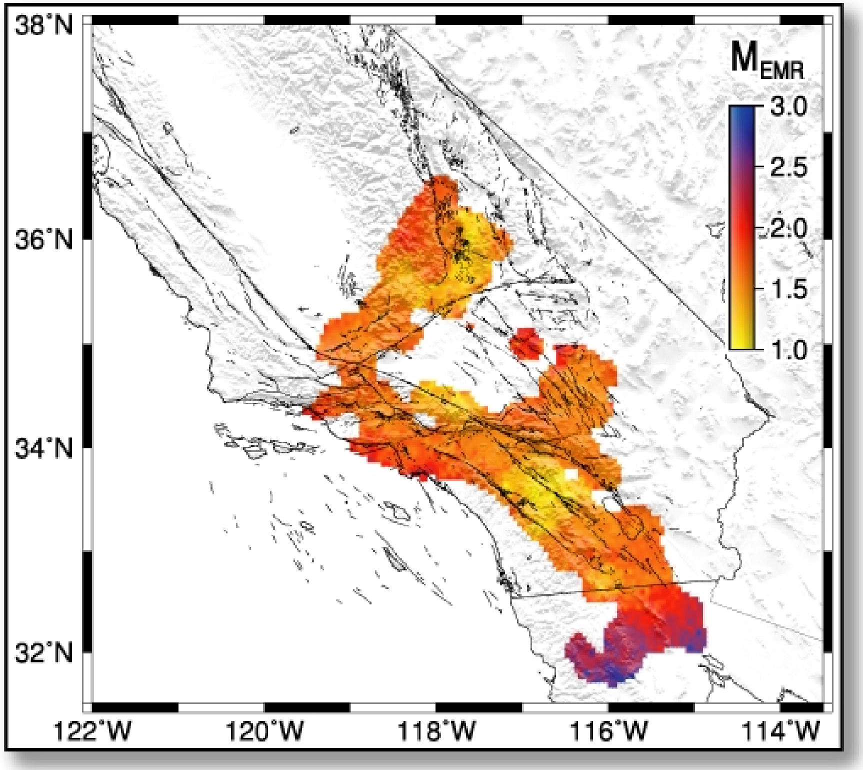
Assumptions:

- Earthquake samples exhibit a GR-distribution
- $M_c$ can be averaged over space (Earthquakes are sampled in circles with radii of several km)
- $M_c$ can be averaged over time (Networks may change during the period of sampling)

Implications:

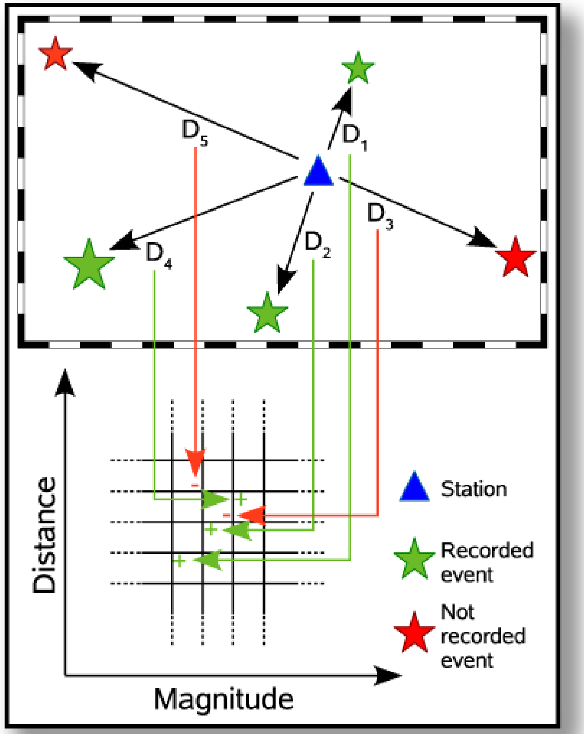
- $M_c$ cannot be determined in low-seismicity areas
- $M_c$ is a function of earthquake samples

# New Method




The “Gutenberg-Richter”-definition is a proxy.

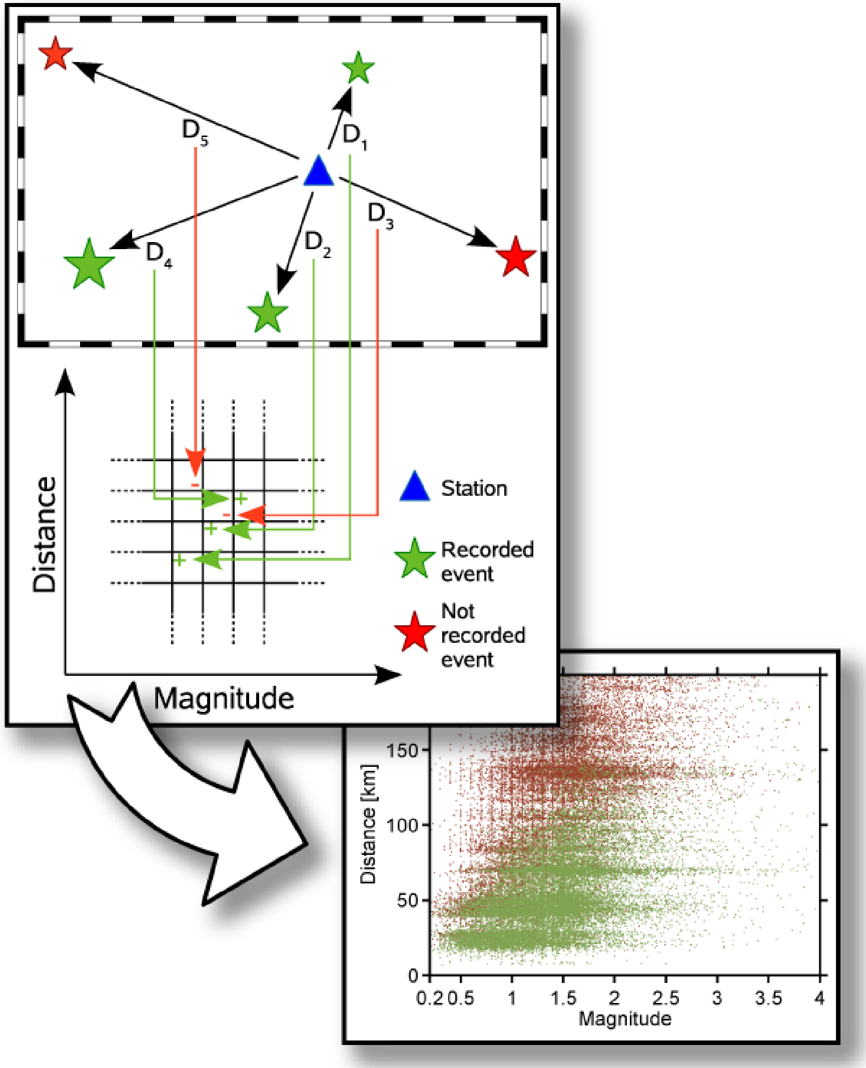
# New Method




The "Gutenberg-Richter"-definition is a proxy.

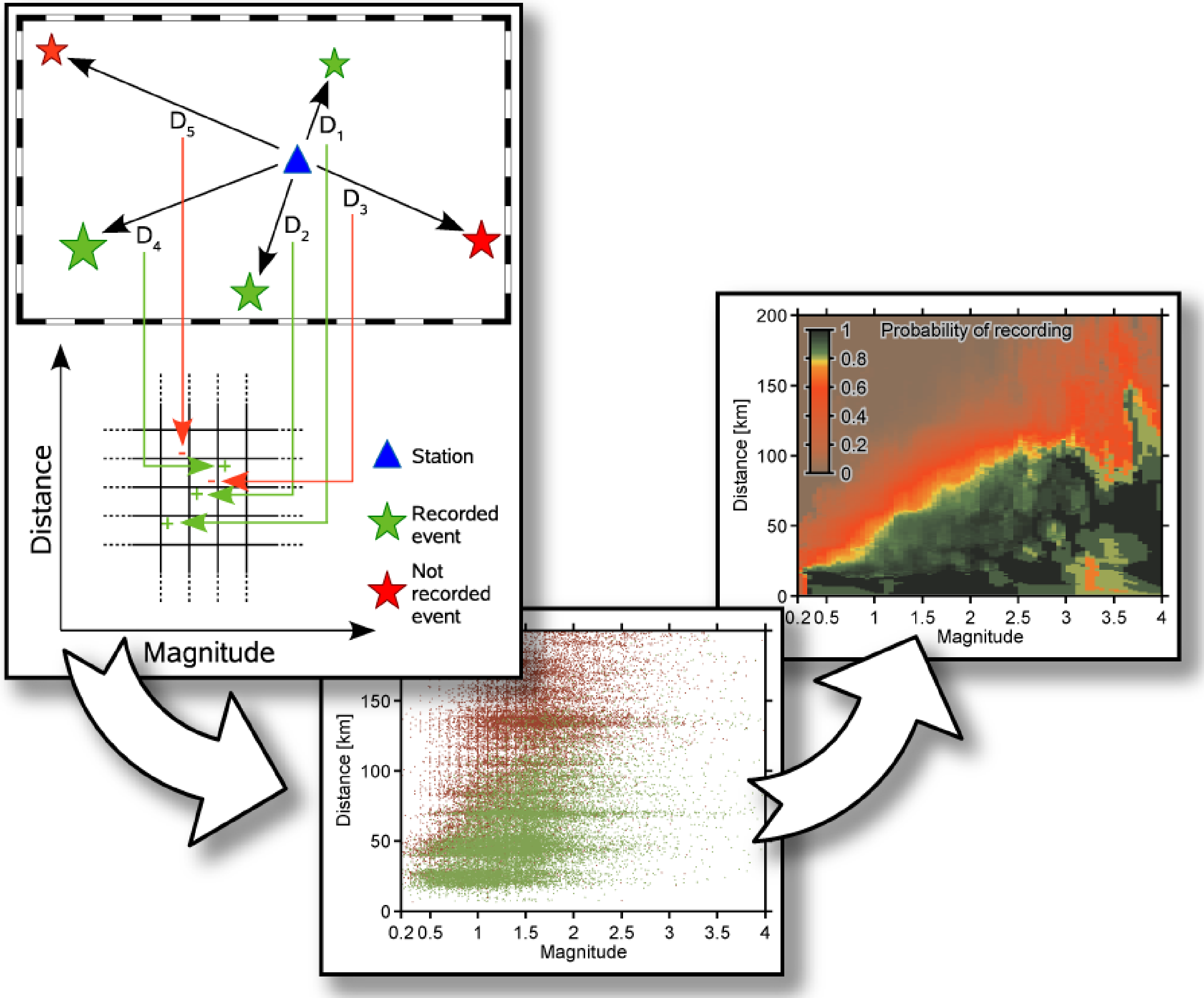
Completeness should be described by the station capabilities of detecting events of certain magnitudes

# New Method



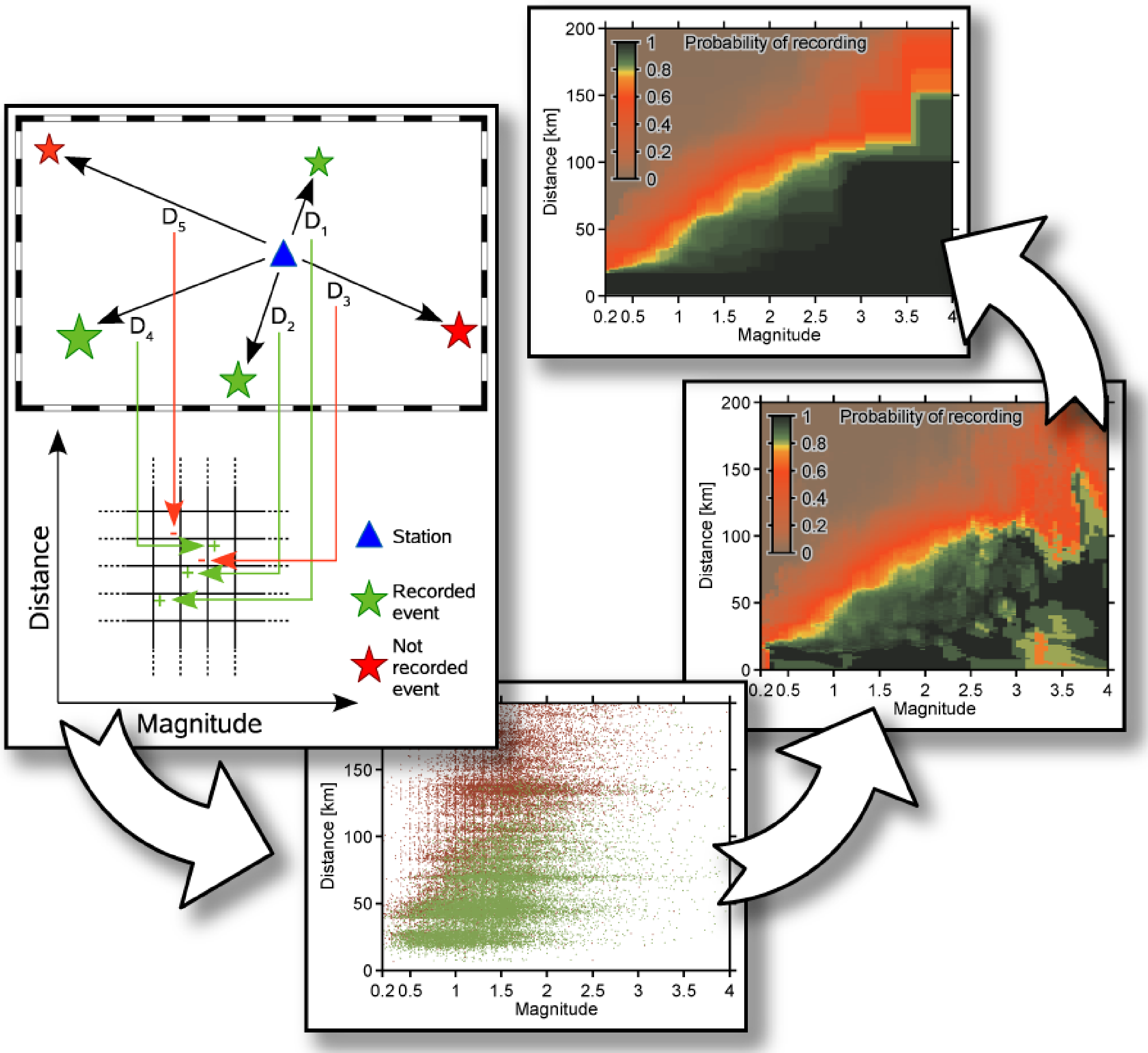
D1
D2
D3
D4
D5
Distance
Magnitude
Station
Recorded event
Not recorded event
Distance [km]
0
50
100
150
0.2 0.5
1
1.5
2
2.5
3
3.5
4
Magnitude

# New Method



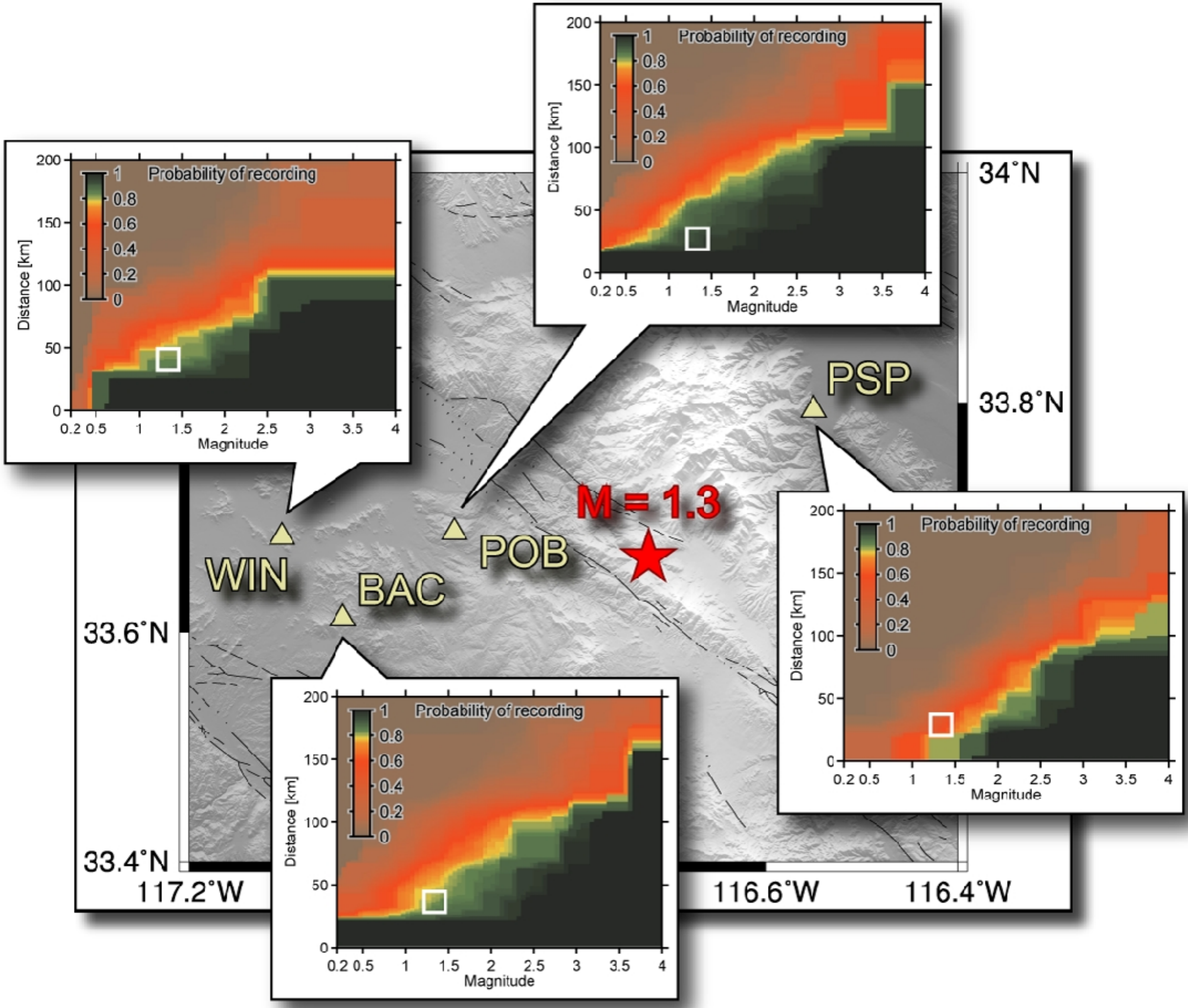
D1
D2
D3
D4
D5
Distance
Magnitude
Station
Recorded event
Not recorded event
Distance [km]
Magnitude
Probability of recording

# New Method

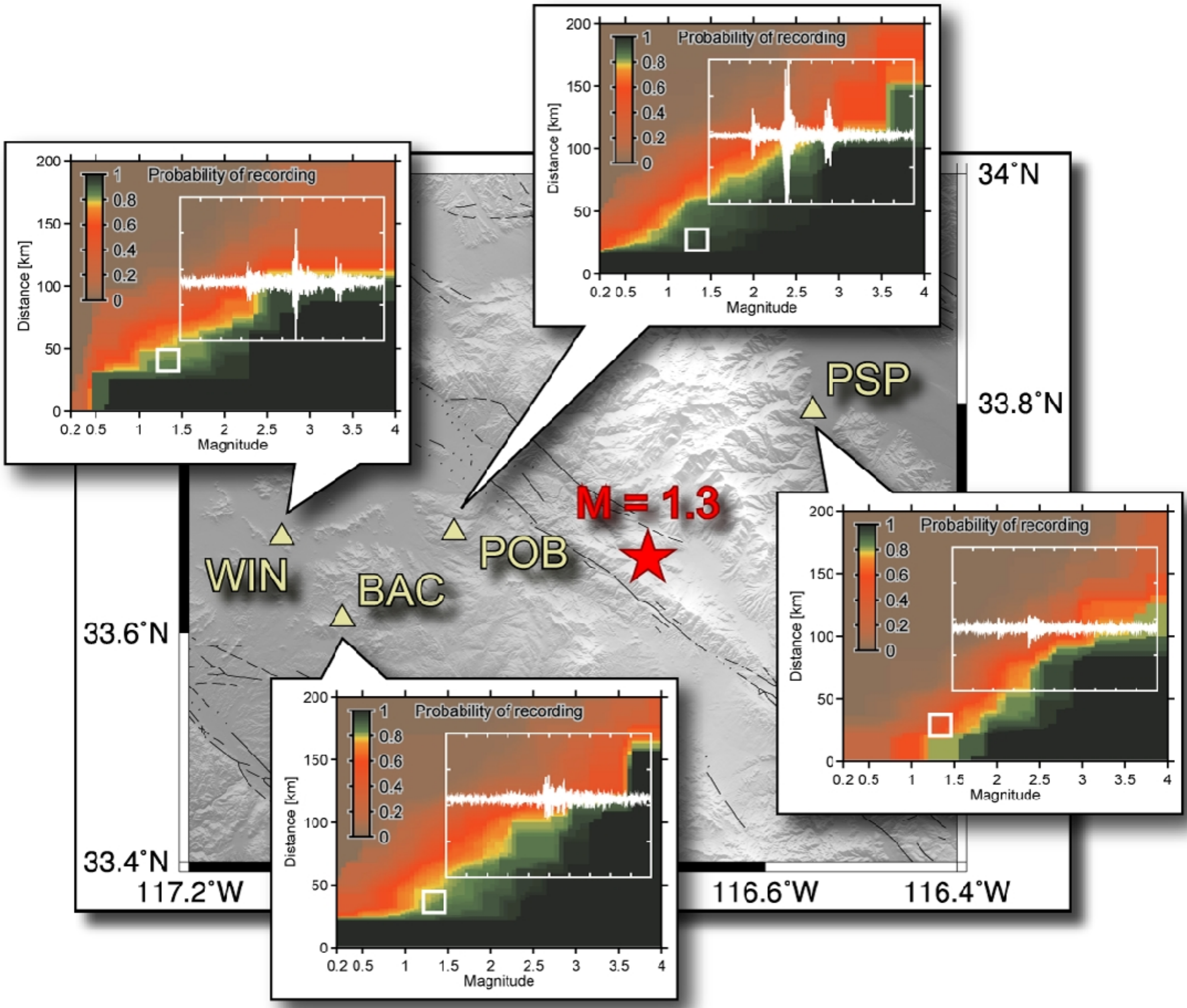

D1
D2
D3
D4
D5
Distance
Magnitude
Station
Recorded event
Not recorded event
Probability of recording
Distance [km]
Magnitude
200
150
100
50
0
0.2 0.5
1
1.5
2
2.5
3
3.5
4
1
0.8
0.6
0.4
0.2
0

SOUTHERN CALIFORNIA EARTHQUAKE CENTER

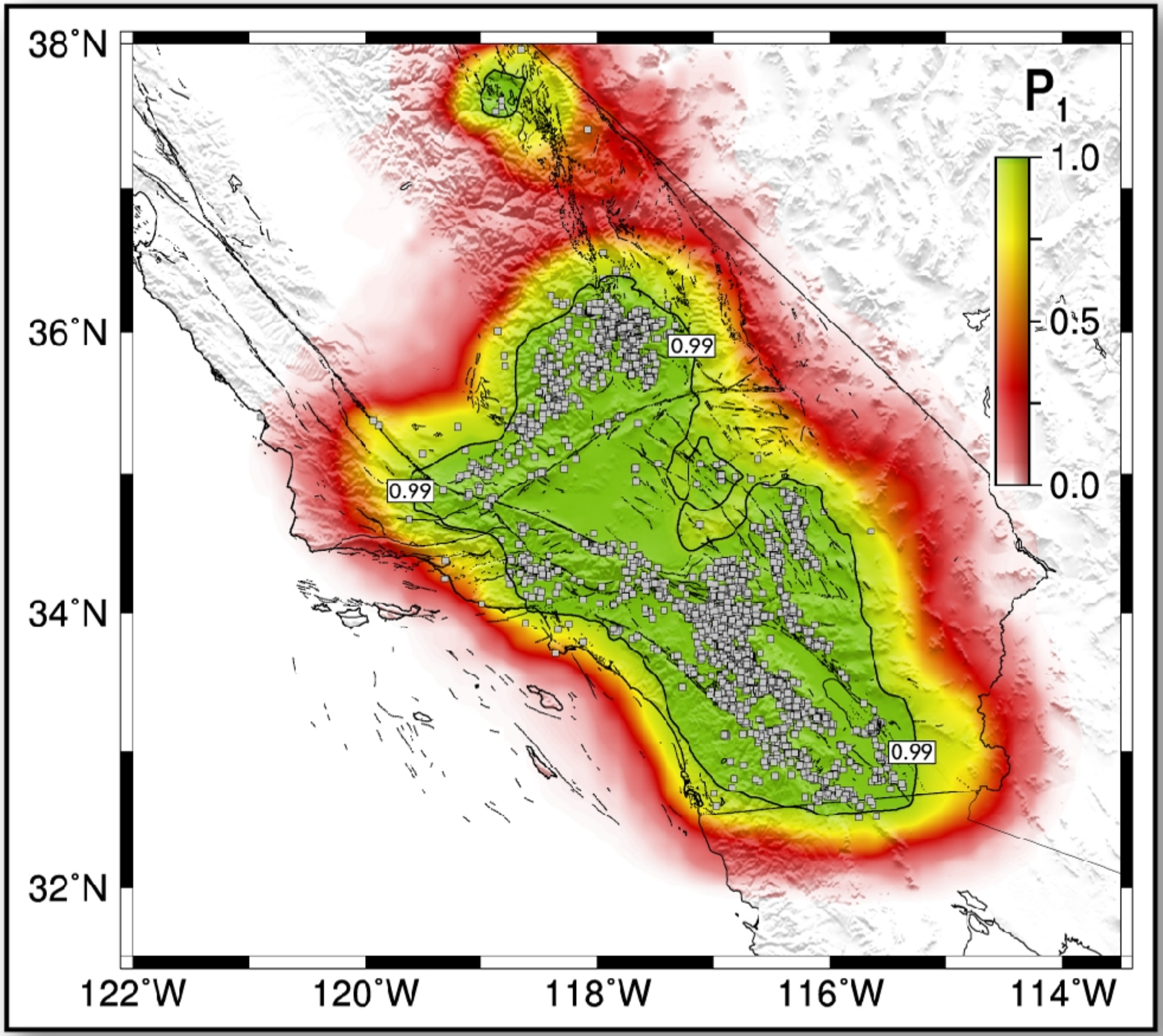
# Station Recording Capabilities



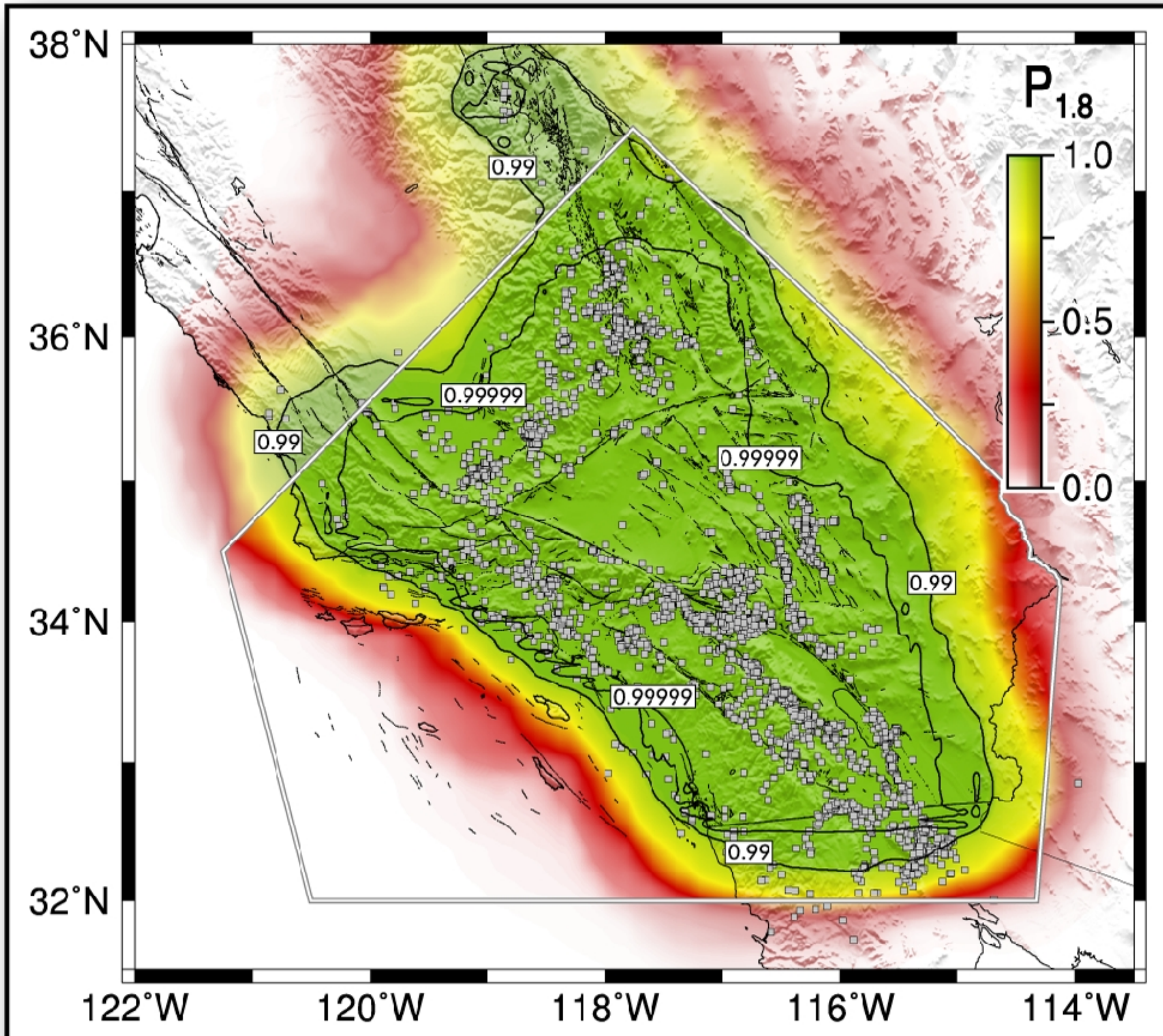
# Station Recording Capabilities



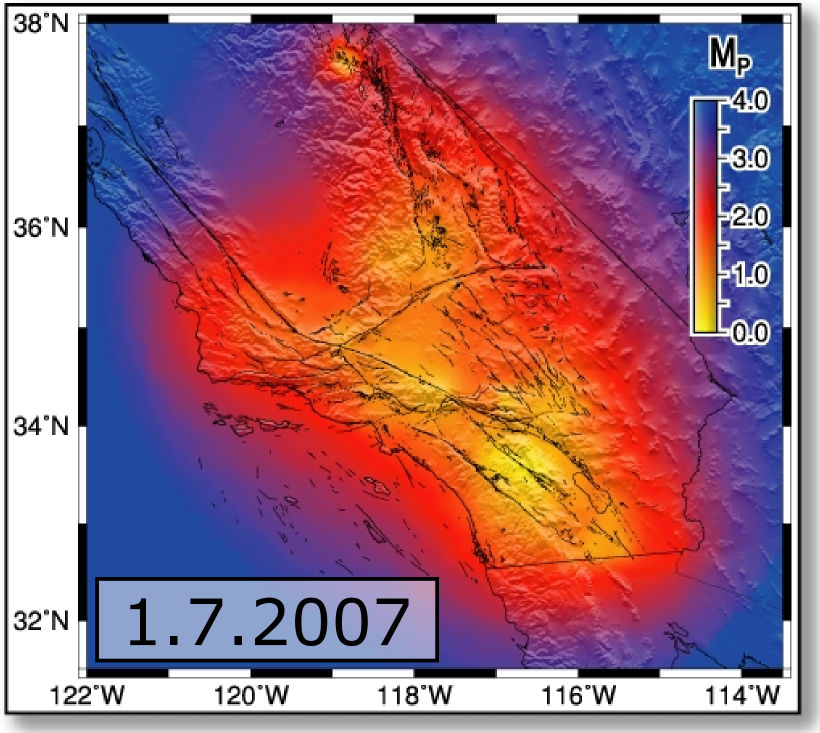
# Probability of Detecting Events



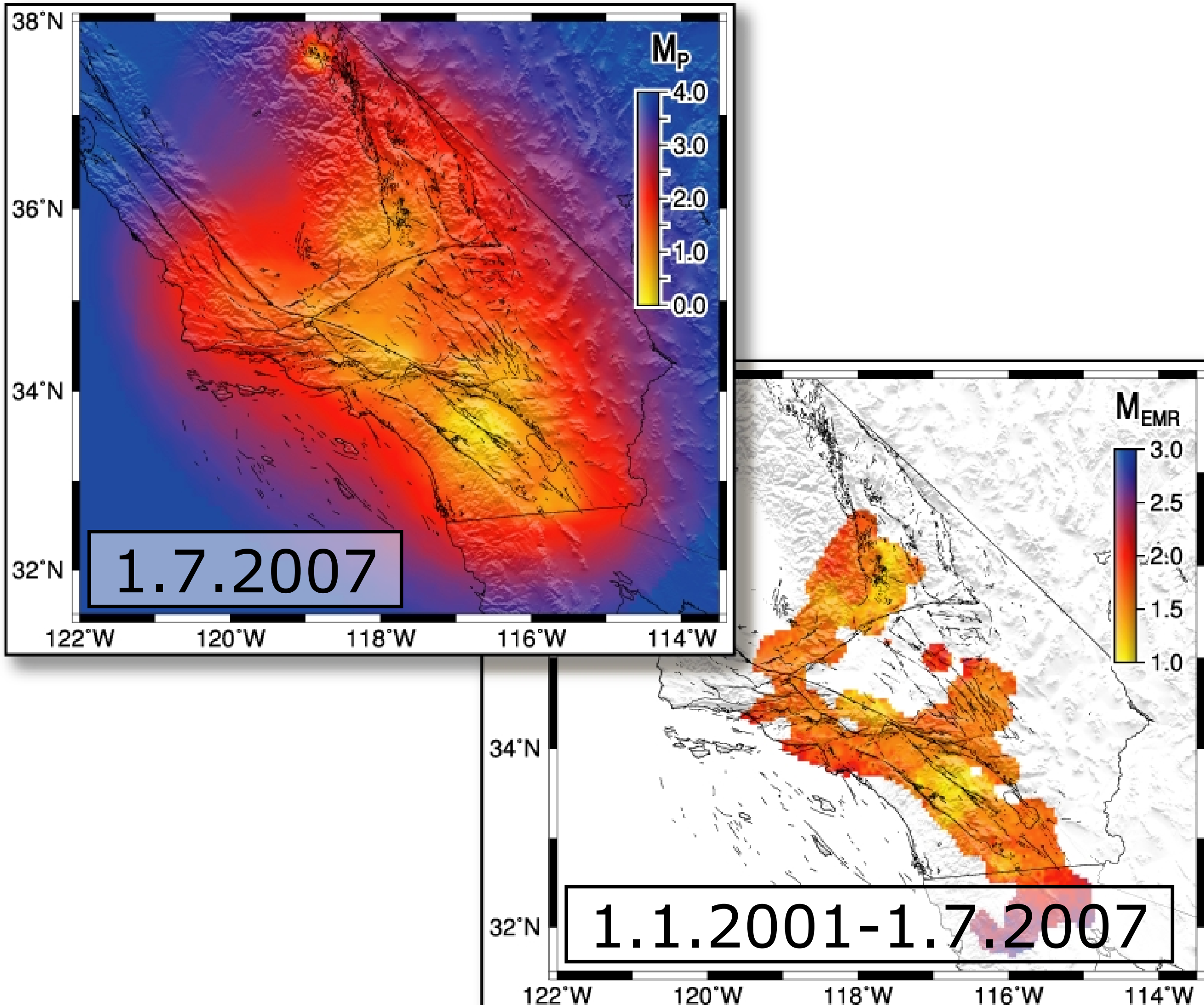
# Probability of Detecting Events



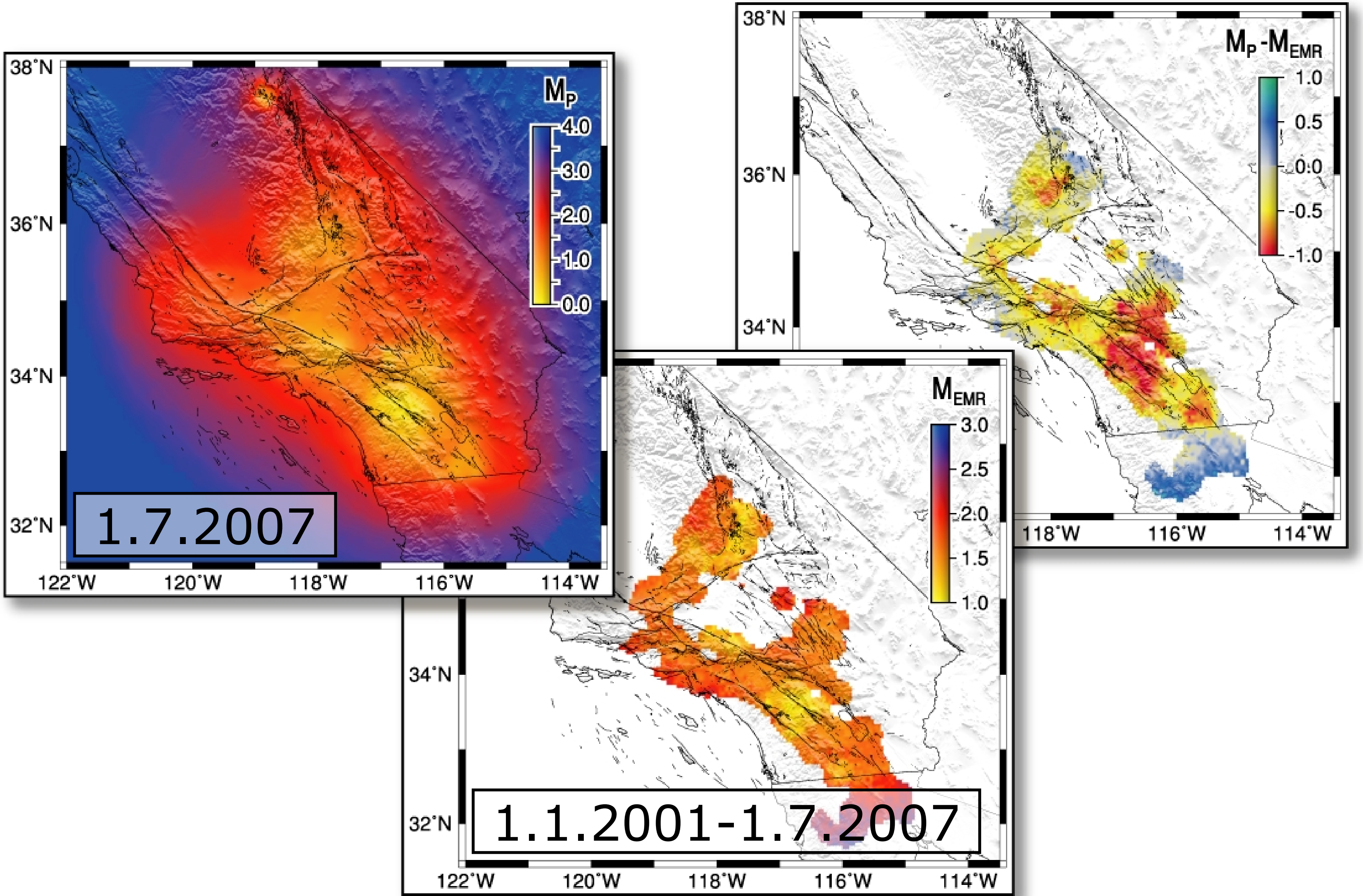
# Magnitude of Completeness



# Magnitude of Completeness



# Magnitude of Completeness

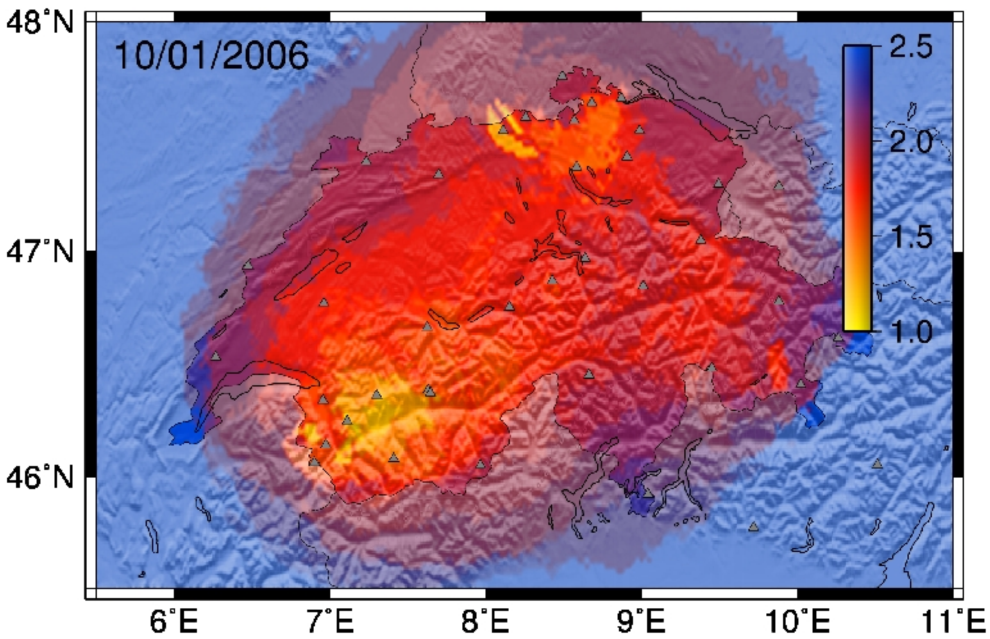


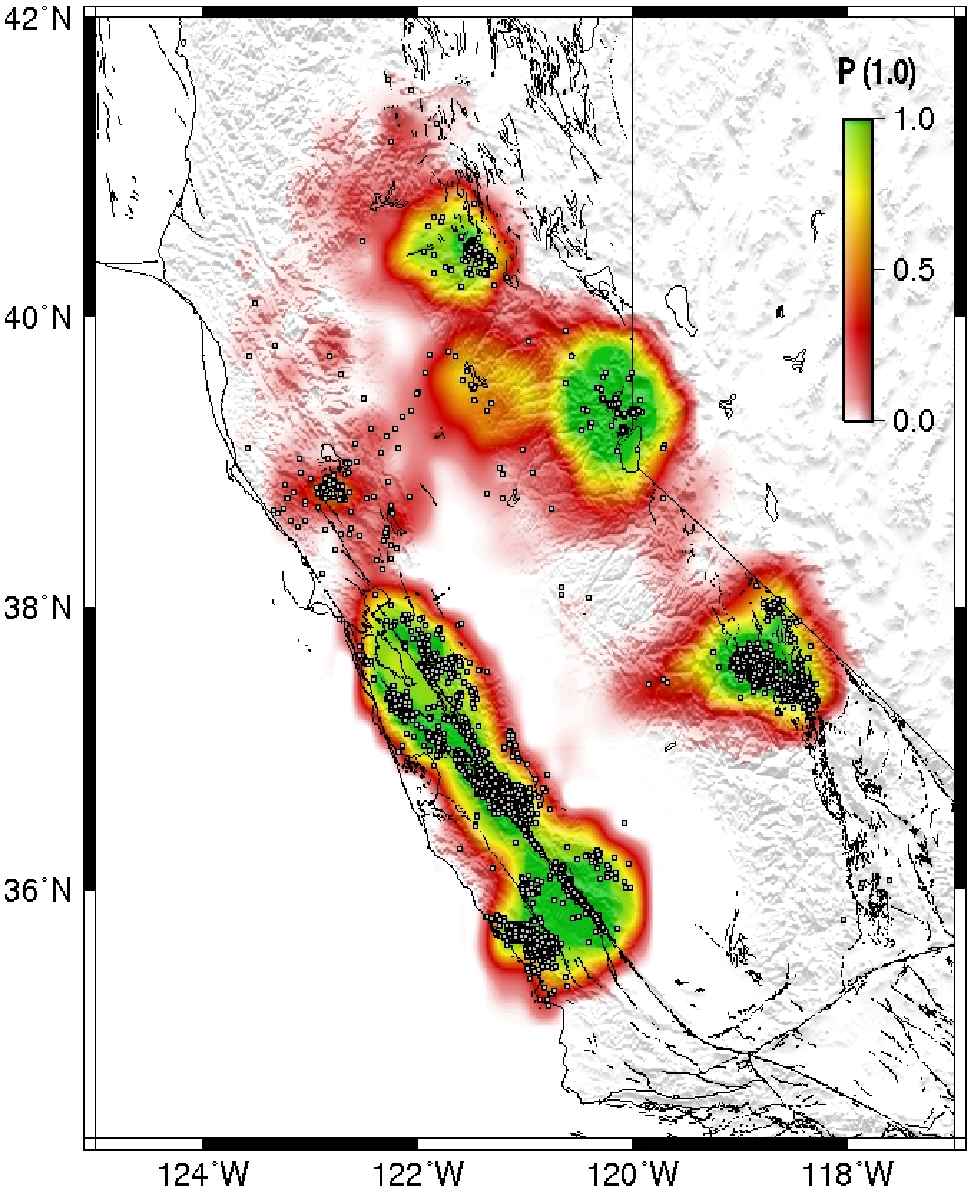
# Other Networks

- Northern California
- Switzerland

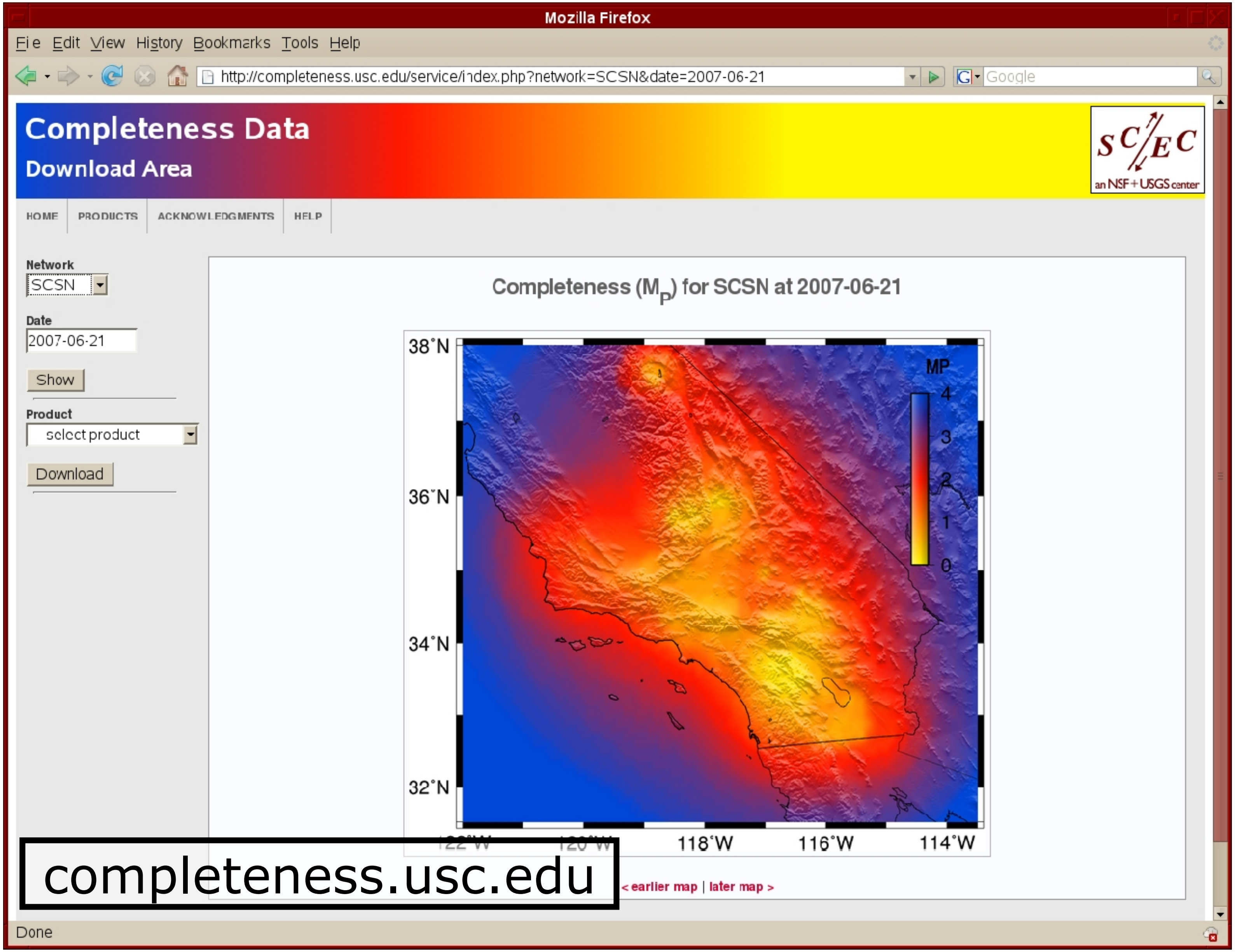
In Progress:

- Friuli (Italy)

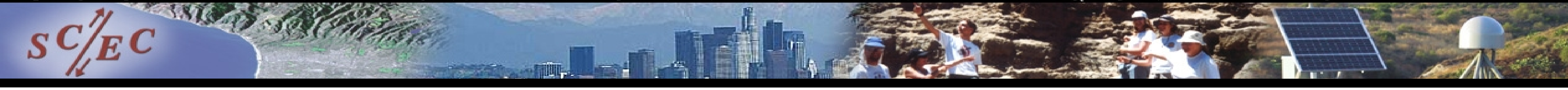


# Webservice




completeness.usc.edu

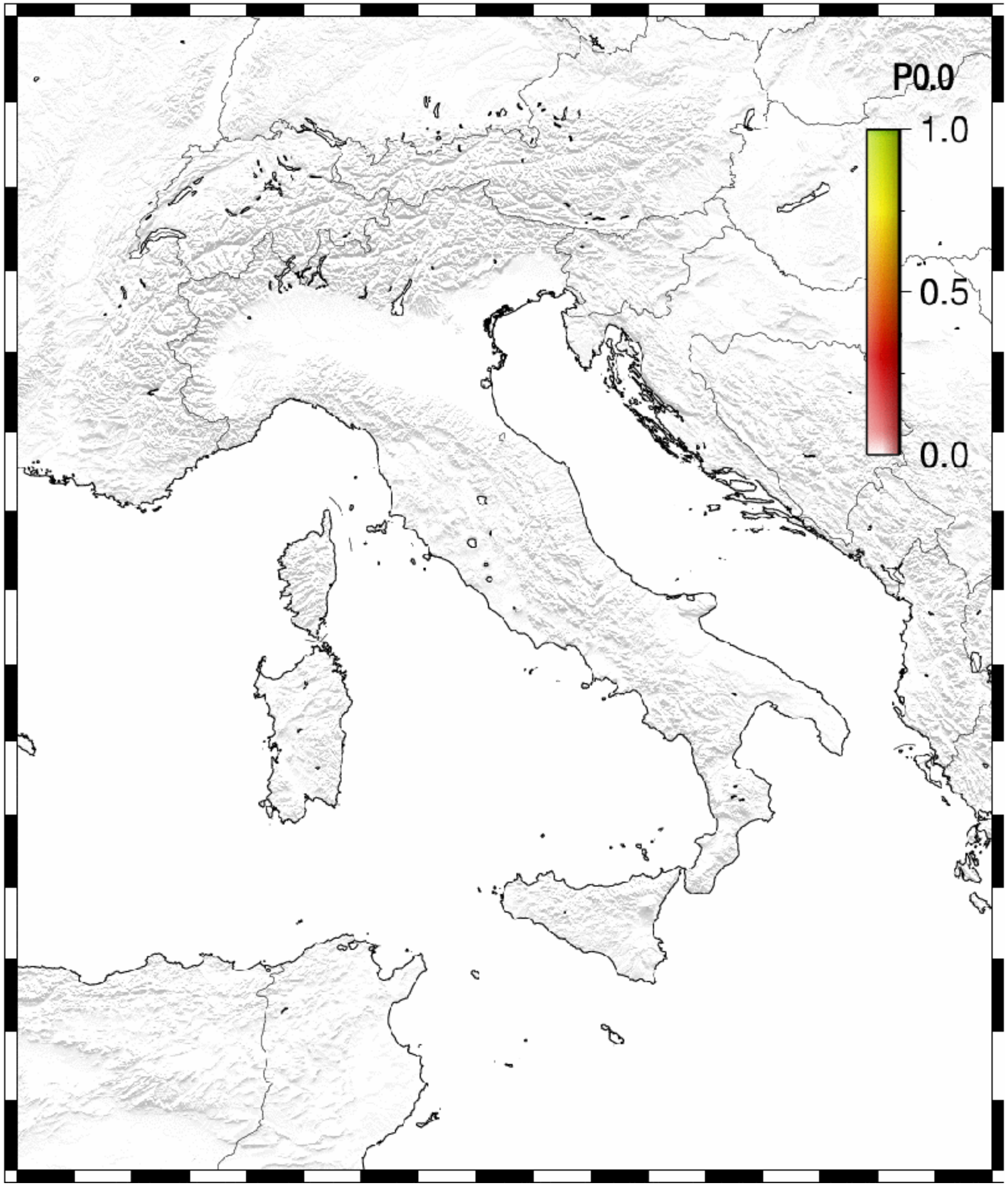



# Italy

INGV Network

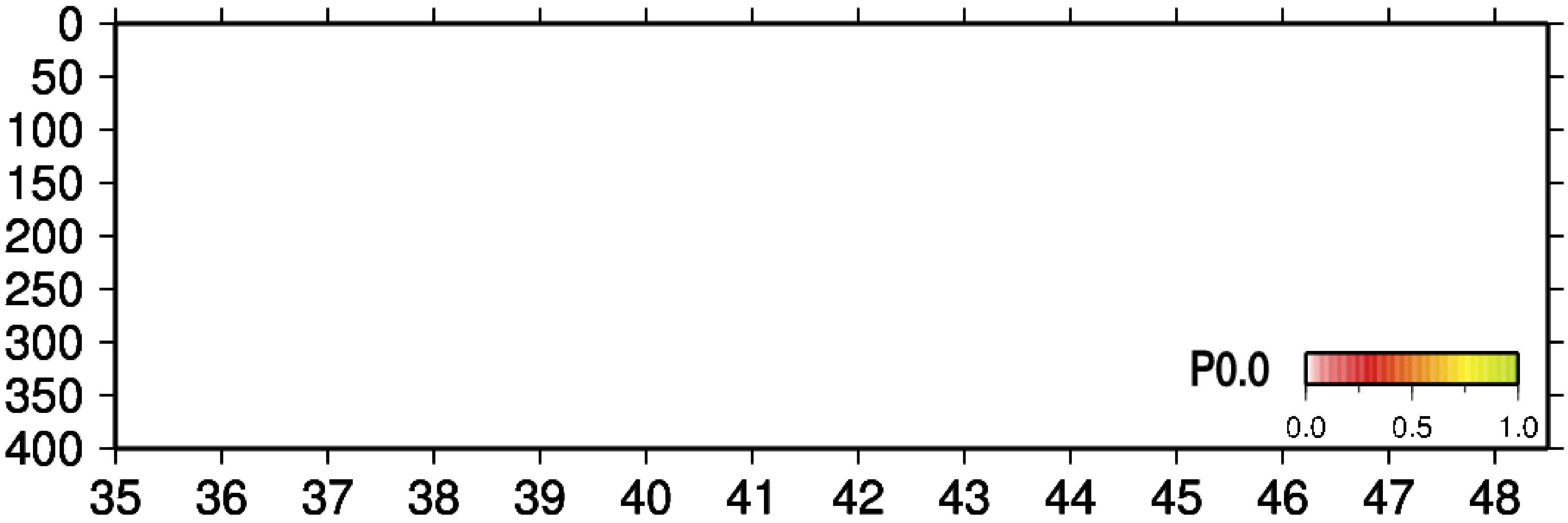
- List of stations
- On/Off-times derived from waveform files
- List of linktypes per station
- INGV earthquake catalog
- Magnitude definition used at INGV

# Detection Probabilities

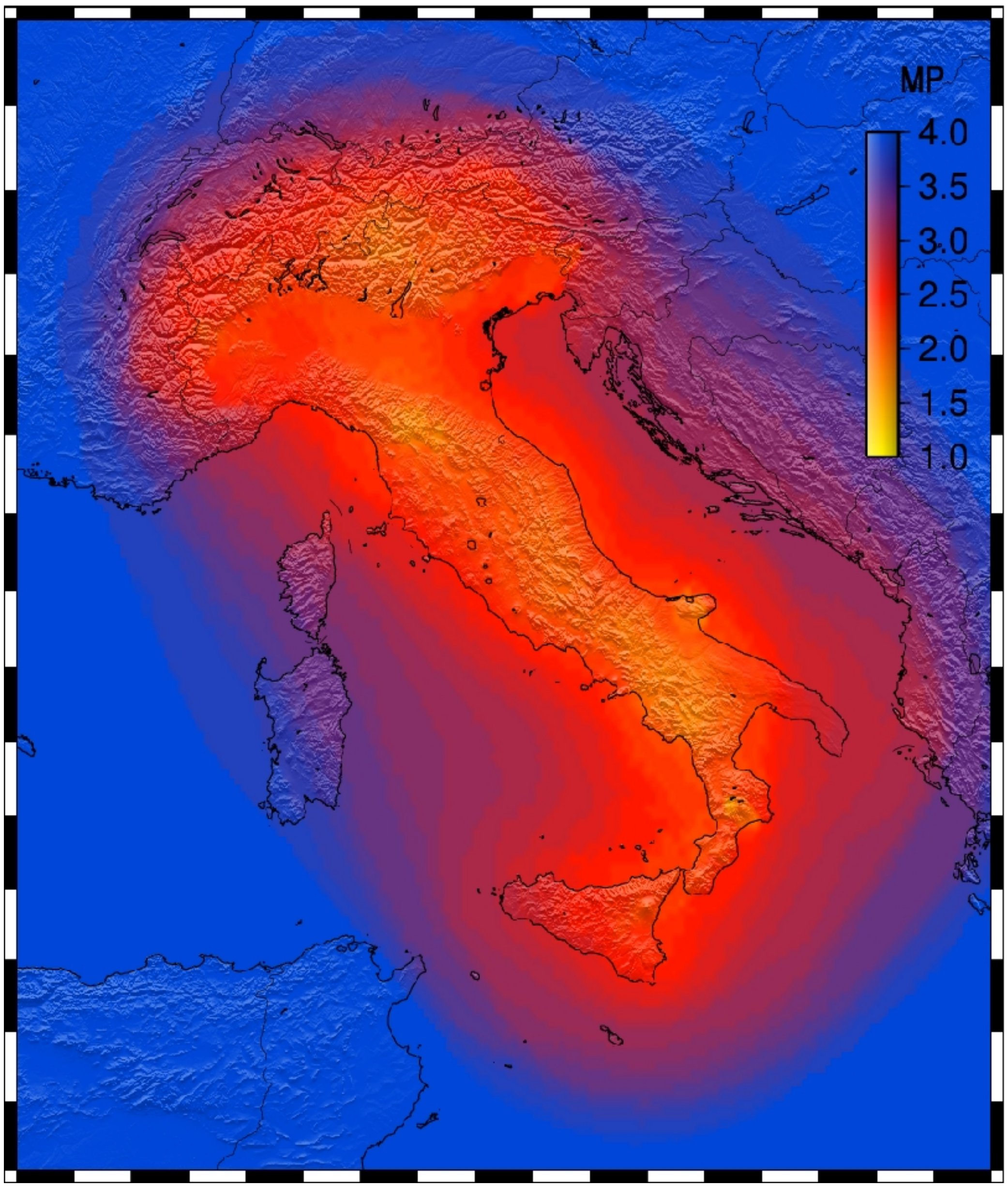


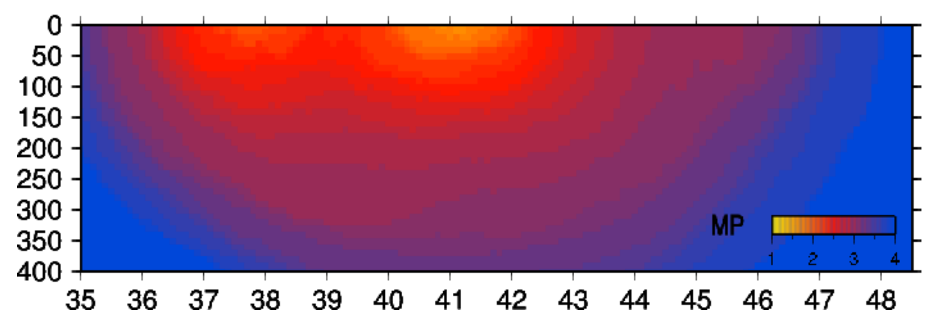
# Detection with Depth

Along longitude 15E

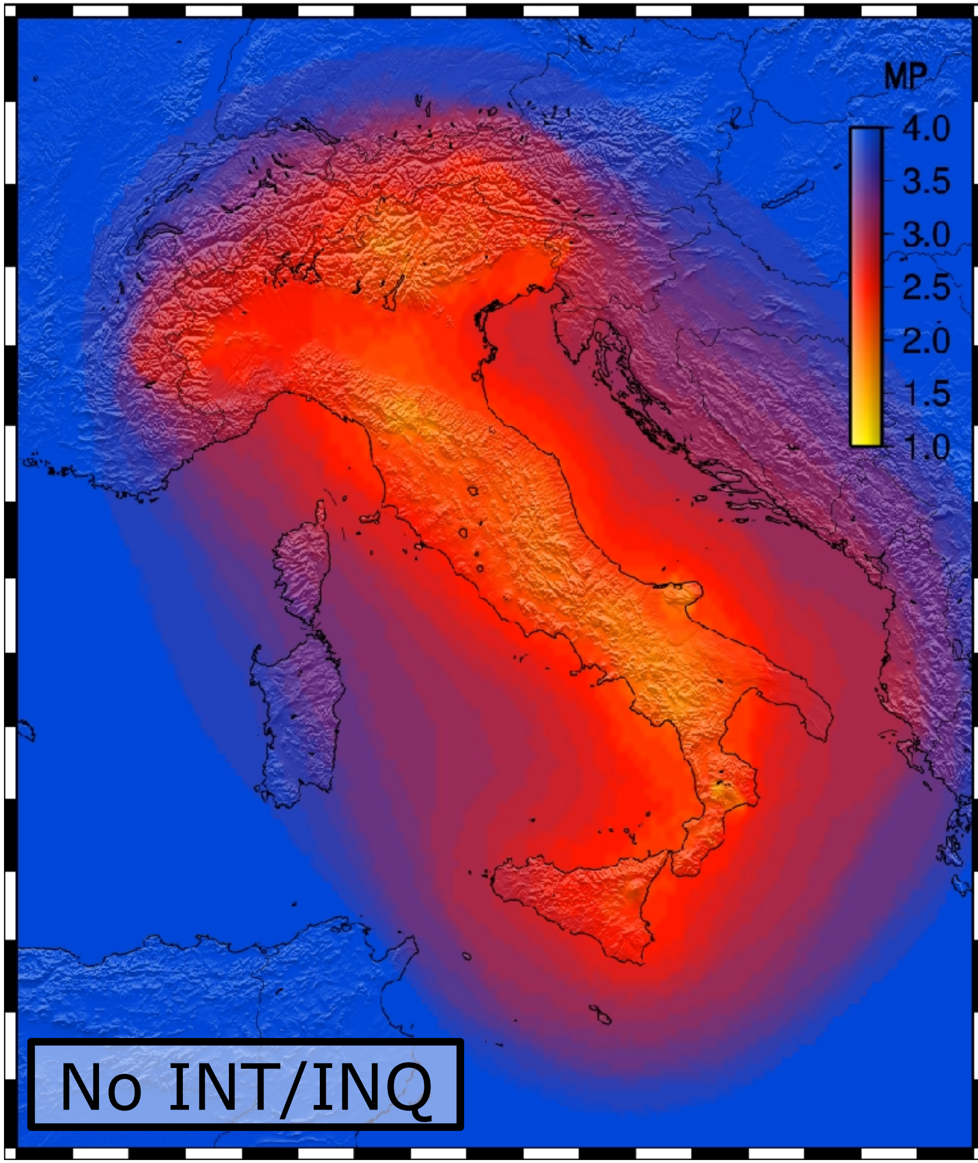


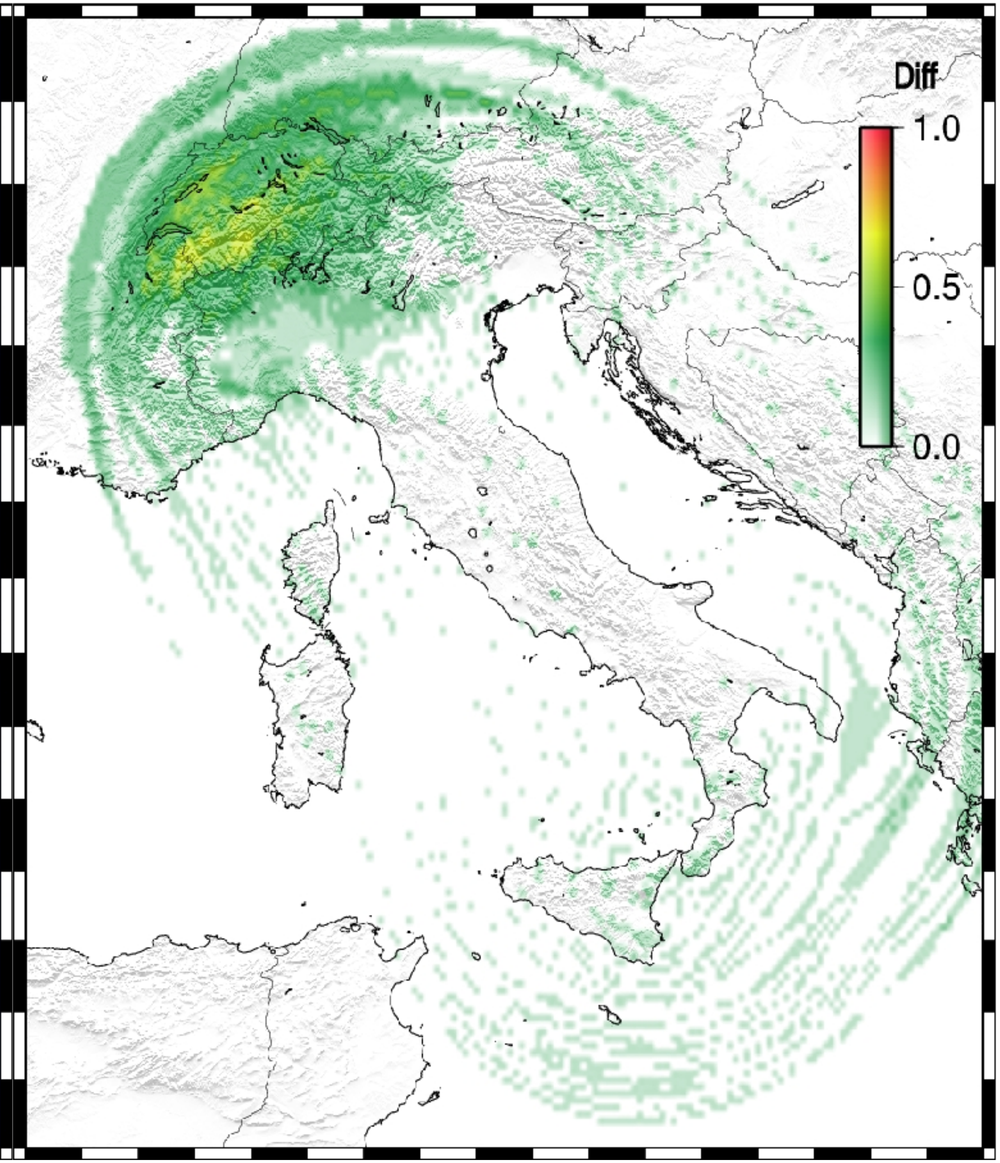
# Completeness



# Scenarios



# CSEP Testing Region Italy

**Rationale**

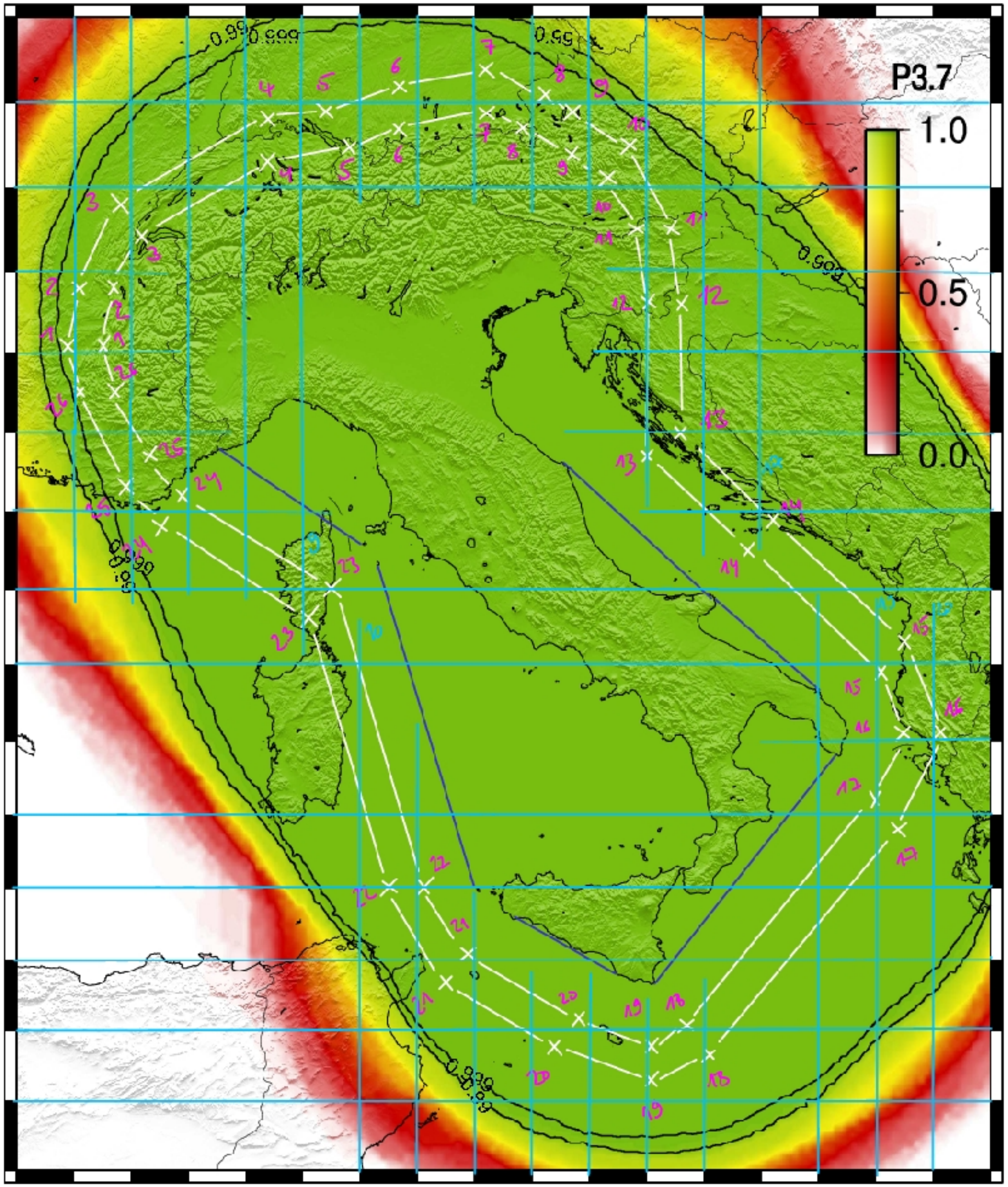
Target area: cover all of Italy
Testing area: extend 50-100km around target area
Collection area: extend further 50km around testing area

**Completeness**

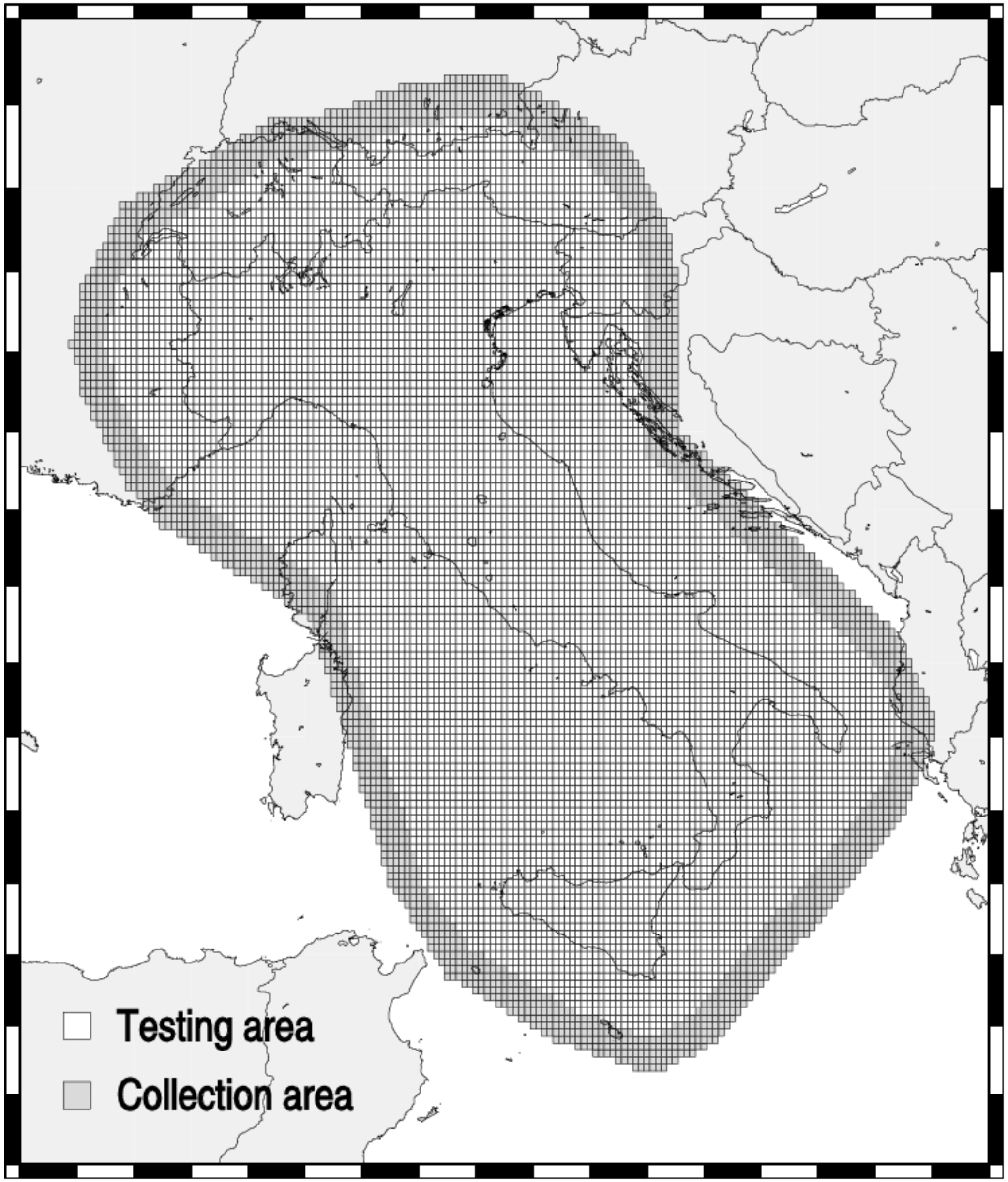
Target magnitude range is M4+

Testing area: 0.999 (99.9%) at M3.7+
Collection area: 0.99 (99%) at M3.7+

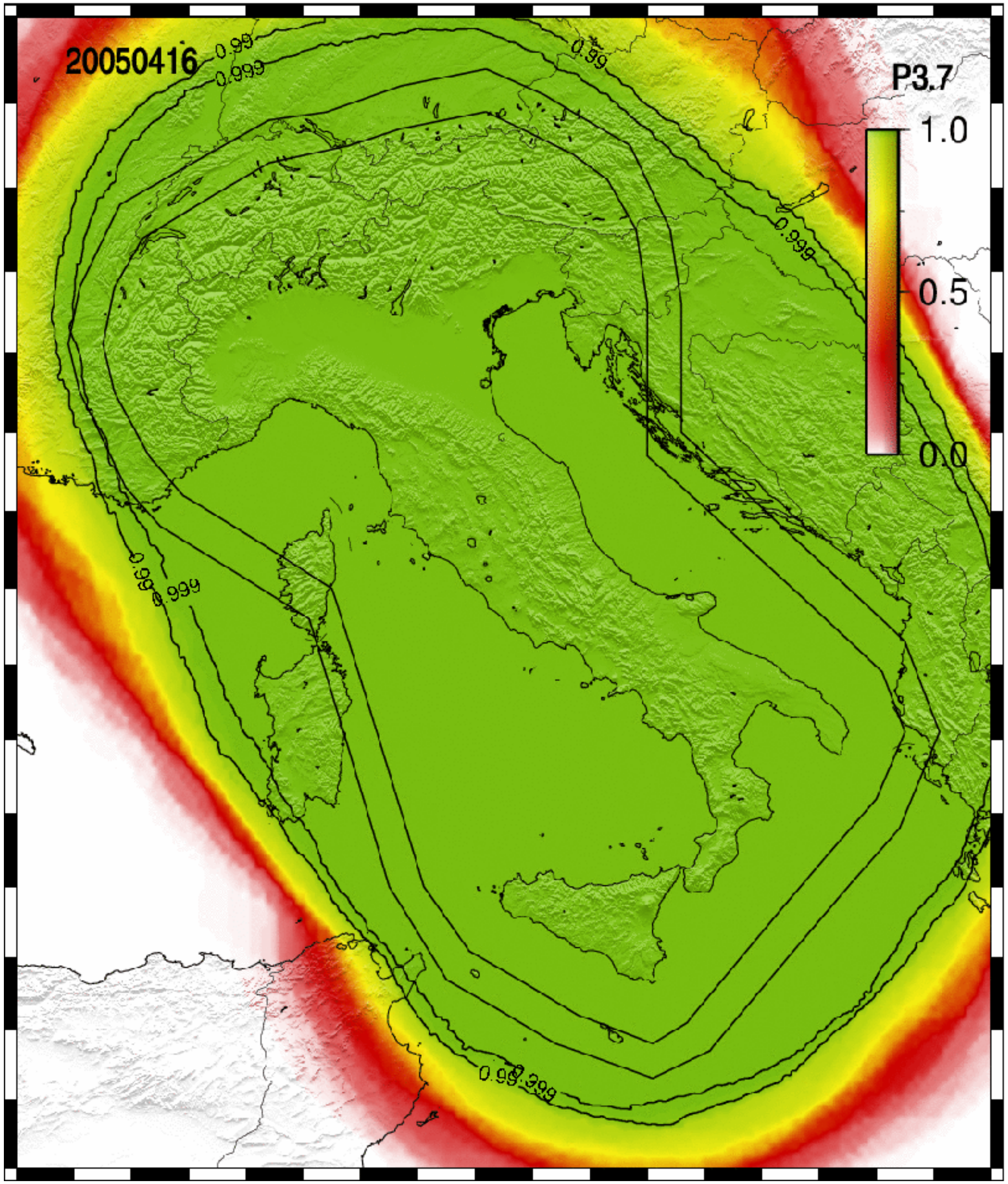
# CSEP Testing Area



# CSEP Testing Area



# CSEP Testing Region Italy



# Summary

New method for estimating completeness

**PROS**:

- No model assumption (Gutenberg-Richter distribution)
  $\rightarrow$ Volcanoes
- No averaging over space and time
  $\rightarrow$ Statement for a particular network configuration
- Full description of completeness changes over space/time
- More “complete” description (Prob. per magnitude)
- Works in low-seismicity areas
- Takes site conditions into account
- Takes localization procedure into account

**CONS**:

- Computationally more intensive that traditional methods

# In Progress

- Investigate completeness of the JMA network
- Define testing area for CSEP
- Implement automatic catalog retrieval
- Set up the CSEP Testing Center in Japan

# Thank You!

Visit our websites:

– www.cseptesting.org
– us.cseptesting.org
– relm.cseptesting.org
– completeness.usc.edu
– www.quakeml.org
– www.quakepy.org